Model Evaluation Workgroup
Technical Memorandum 3a

Evaluation of Flows, Loads, Initial Conditions, and Boundary Conditions

Prepared by:

Wisconsin Department of Natural Resources

February 20, 2001

ACKNOWLEDGEMENTS

This technical memorandum was edited by Mark Velleux of the Wisconsin Department of Natural Resources (WDNR). Extensive portions of this report were prepared in collaboration with Limno-Tech, Inc. (LTI) on behalf of the Fox River Group of Companies (FRG) under the terms of the January 31, 1997 Agreement with the State of Wisconsin. The contributions of LTI staff are gratefully acknowledged. Funding for LTI was provided by the FRG.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION AND SUMMARY

This technical memorandum is provided in partial fulfillment of the Memorandum of Agreement (Agreement) between the State of Wisconsin and seven paper companies (Companies), dated January 31, 1997.

Model evaluations are to be undertaken according to the procedures discussed in the "Workplan to Evaluate the Fate and Transport Models for the Fox River and Green Bay" (Workplan). The Workplan was submitted by Limno-Tech, Inc. ("LTI") on behalf of the Companies to the Wisconsin Department of Natural Resources (WDNR) on September 19, 1997. The Workplan was conditionally approved by WDNR on September 26, 1997.

The Agreement calls for the existing suite of Lower Fox River and Green Bay models to be evaluated. For the purpose of model evaluation, the existing models are identified in Table 1-1. Technical Memorandum 1 (1998) provides an overview of the model evaluation process. The existing models, as well as any proposed alternatives, are defined in Technical Memorandum 1 as a suite of models that have:

- consistent spatial and temporal domains;
- consistent representations of state variables for particles and contaminants that allow completion of short-term and long-term, retrospective simulations; and
- consistent use of the most complete evaluation of external forcing functions, boundary conditions, and initial conditions available.

Flows, solids and PCB loads, initial conditions, and boundary conditions were estimated and applied in existing models for two sections of the Lower Fox River (upstream and downstream of the DePere Dam) and for Green Bay. As part of the overall model evaluation process, estimates for these model inputs were developed by the "Model Evaluation Workgroup" (Workgroup) as part of Task 2 of the Workplan and related efforts. This report summarizes the results of those efforts and evaluates the representation of flows, loads, initial conditions, and boundary conditions in the existing models relative to the Task 2 and related effort results.

The comparisons presented in this memorandum between existing and Task 2 flows and loads are for the short-term simulation period (1989-1995). Summary table comparisons, time series comparisons, and distribution comparisons are presented. For clarity, a sub-period was selected for graphical presentation of time series comparisons. The data-rich Green Bay Mass Balance Study (GBMBS) period (April 1, 1989 through March 31, 1990) was selected as the period for comparison. This 12-month period provides a brief and clear yet representative comparison.

A key feature of this process is that the results of Task 2 (and related efforts) are considered to be the standard against which the flows, loads, initial conditions, and boundary conditions specified in the existing models are evaluated. Therefore, if inputs in the existing models differ significantly on average or at specific times or points in space (in the collective judgment of the

Workgroup) from the results of Task 2, existing model inputs will be replaced by Task 2 inputs. If inputs in the existing models do not differ significantly from the results of Task 2, existing model inputs will be accepted. In some cases, there is no corresponding Task 2 work product for evaluation. In those situations, the existing representation of that model feature will be accepted.

The calibration of the existing models depends in part on the values assigned to model inputs such as flows, loads, initial conditions, and boundary conditions. Should it be necessary to replace existing model inputs, it may be necessary to undertake limited calibration efforts before proceeding with the short-term and long-term simulation evaluations of Task 3. These limited calibration efforts (if needed) are not intended to be extensive or otherwise replace Task 6 of the model evaluation process. They would employ the same methodologies that were used to calibrate the models with the existing inputs. Parameter changes would be the minimum needed to accommodate Task 2 inputs. Any limited calibration will be documented. Significant model calibration efforts, if indicated by the results of Task 3 of the Workplan, are intended to occur only as part of Task 6.

Table 1-1. Identification of Existing Models for the Lower Fox River and Green Bay

Model	*Spatial Domain*	*Framework*	*Input Files*	*Source*
UFRM	Lower Fox River: Lake Winnebago to the DePere Dam	WASP 5.1	o-ufpa96.inp	WDNR, 1997; Steuer et al. 1995
LFRM	Lower Fox River: DePere Dam to Green Bay	IPX 2.7.0[1]	lf8995pa.inp	WDNR, 1997; Velleux et al. 1995
GBTOX Suite of Models	Green Bay: Lower Fox River to Lake Michigan interface	GBCL GBOCS GBTS GBTOX	89c1_014.inp re-c3.inp new.inp re-c3.inp	Bierman et al. 1992; DePinto et al. 1993; Raghunathan, 1994
GBFood	Green Bay: Lower Fox River to Lake Michigan interface	FDCHAIN (5.1)	128d.inp 3a8.inp 3b8.inp 48.inp	Connolly, et al.1992; HQI, 1995

1 In its initial release, this version of the IPX framework was identified as Release 1 (R1). IPX 2.7.0 maintains the full feature set necessary to reproduce the results presented by WDNR (1997).

2.0 FLOWS AND LOADS

Flows and solids and PCB loads delivered to the Lower Fox River and Green Bay originate from numerous sources, including watershed runoff, point sources, and in the case of solids, internal production. This section provides a comparison between existing and Task 2 estimates of loads and flows to the Lower Fox River and Green Bay for each source: watershed, point source and, in the case of solids, internal production.

2.1 LOWER FOX RIVER

The estimated flows and loads to the Lower Fox River serve as inputs to two models: the Upper Fox River Model (UFRM) for Lake Winnebago to the DePere Dam; and the Lower Fox River Model (LFRM) for the DePere Dam to the river mouth. The following discussion of watershed, point source, and internal loads and flows addresses each of these modeled reaches separately.

2.1.1 Watershed Flows and Loads

Watershed flows and solids loads to the Lower Fox River between Lake Winnebago and DePere Dam were estimated during development of the UFRM (Steuer et al. 1995). Watershed flows, or tributary inflow, were estimated from the difference between DePere and Appleton flows estimated from acoustic velocity meter measurements. This flow difference was proportioned to the Kankapot Creek and Plum and Apple Creeks based on watershed subbasin areas. Watershed solids loads were also estimated for Kankapot Creek and Plum and Apple Creeks. The solids loads were based on monitoring conducted on Silver Creek (adjacent to the Lower Fox River watershed). Watershed PCB loads were considered negligible relative to other sources and treated as zero in the UFRM.

Watershed flow contributions to the Lower Fox River between the DePere Dam and Green Bay were considered negligible relative to the flow over the DePere Dam and treated as zero in the LFRM (Velleux and Endicott, 1994). Watershed solids loads were estimated for this reach by WDNR. The East River solids load was estimated as 6.45 million kg/yr and loads from the remaining Lower Fox River watershed downstream of the DePere Dam were considered negligible and treated as zero. The East River loads were parameterized as a constant load in the LFRM model. Watershed PCB loads were considered negligible relative to other sources and treated as zero in the LFRM.

To estimate watershed inputs for the purpose of evaluating the existing models, watershed flows and solids loads to the Lower Fox River between Lake Winnebago and Green Bay were examined in Task 2a. In this task, the Soil and Water Assessment Tool (SWAT) was applied to estimate solids loads and flows to the Lower Fox River for both reaches. This model uses watershed characteristics such as land use, crop rotations and soil type along with climatic data to predict watershed flows and solids loads on a daily basis. Fox-Wolf Basin 2000 (FWB2000) developed the SWAT application. These load estimates are presented in "Technical Memorandum 2a: Simulation of Historical and Projected Total Suspended Solids Loads and

Flows to the Lower Fox River, N.E. Wisconsin, with the Soil and Water Assessment Tool (SWAT)" (TM2a) (FWB2000, 1998).

It should be noted that the TM2a watershed flow estimates required preprocessing prior to use for model evaluations to prevent the estimation of negative flows from Lake Winnebago. The preprocessing of TM2a watershed flows is described in Appendix A. To estimate flows from Lake Winnebago, the TM2a flow estimates were subtracted from the USGS gage at Rapide Croche. To prevent negative flow estimates at Lake Winnebago, daily TM2a flows were averaged over a 4-day period with daily weighting factors of 40/20/20/20 percent. In other words, for watershed flows estimated in TM2a for on Day 1, 40% is assigned to Day 1, and Days 2-4 each receive 20% of the TM2a Day 1 flow. TM2a watershed solids load estimates were also preprocessed according to the 4-day averaging approach to be consistent with the preprocessing of the TM2a watershed flow estimates.

Table 2-1 compares the existing and TM2a watershed flows upstream of the DePere Dam for the 1989-1995 period. The flows for the 1989-1990 period are compared graphically in Figure 2-1. TheTM2a flows are more variable than the existing loads. The maximum 4-day averaged TM2a flow is 194 m^3/s during the 1989-95 period versus a maximum of 14 m^3/s for the existing flows. Figure 2-2 compares the inverse log normal cumulative distribution functions of these values for the 1989-95 period. The y-axis coordinates of the distribution represent the magnitude of the value on a logarithmic scale. The x-axis coordinates of the distribution represent the number of standard deviations away from the mean. The slope of the distribution indicates the variability of the data; a steeper slope reflects a greater variability). The median of the distribution is the y-axis value at a Z value of 0 (on the x-axis). The mean flows estimated in TM2a are approximately 35% greater than the existing flows. The TM2a flows also exhibit a large variability compared to the existing flows.

Table 2-2 compares existing and TM2a watershed flows downstream of the DePere Dam for the 1989-95 simulation period. Watershed flows were treated as zero in the existing model. The TM2a flows for 1989-90 are presented in Figure 2-3. These flows show variability similar to the flows for the river upstream of the DePere Dam. Figure 2-4 presents the inverse long normal cumulative distribution functions of the TM2a flows for 1989-95.

Watershed flows are an important component of the overall water balance in the Lower Fox River between Lake Winnebago and the Green Bay. Based on TM2a results, watershed flows constitute 5.9% of the total stream flow. Approximately 16% of the time, there is a 10% or greater difference between existing mainstem flow estimates at Lake Winnebago and estimates incorporating TM2a watershed flows. Approximately 27% of the time, there is a 10% or greater difference between existing mainstem flow estimates at the mouth and estimates incorporating TM2a watershed flows (see Appendix A for further detail). Because the volume and highly variable nature of watershed flows have the potential to influence the results of short-term and long-term contaminant transport simulations, the overall 60% difference between the existing watershed flows and those presented in TM2a is considered significant. Therefore, the Model Evaluation Workgroup recommends that the UFRM and LFRM be evaluated using the TM2a results with 4-day averaging to define watershed flow inputs.

Table 2-1. Comparison of Estimates for the 1989-1995 Simulation Period: Watershed Flows upstream of the DePere Dam

Flow Summary	***Existing***	***TM2a***	***TM2a 4-day Average***
Minimum (m^3/s)	0.13	0.0	0.0
Median (m^3/s)	3.0	0.8	0.8
Mean (m^3/s)	3.7	5.0	5.0
Maximum (m^3/s)	14	477	194

Table 2-2. Comparison of Estimates for 1989-95 Simulation Period: Watershed Flows downstream of the DePere Dam

Flow Summary	***Existing****	***TM2a***	***TM2a 4-day averaged***
Minimum (m^3/s)	0	0.0	0.0
Median (m^3/s)	0	0.6	0.7
Mean (m^3/s)	0	4.0	4.0
Maximum (m^3/s)	0	404	171

*Loads treated as zero

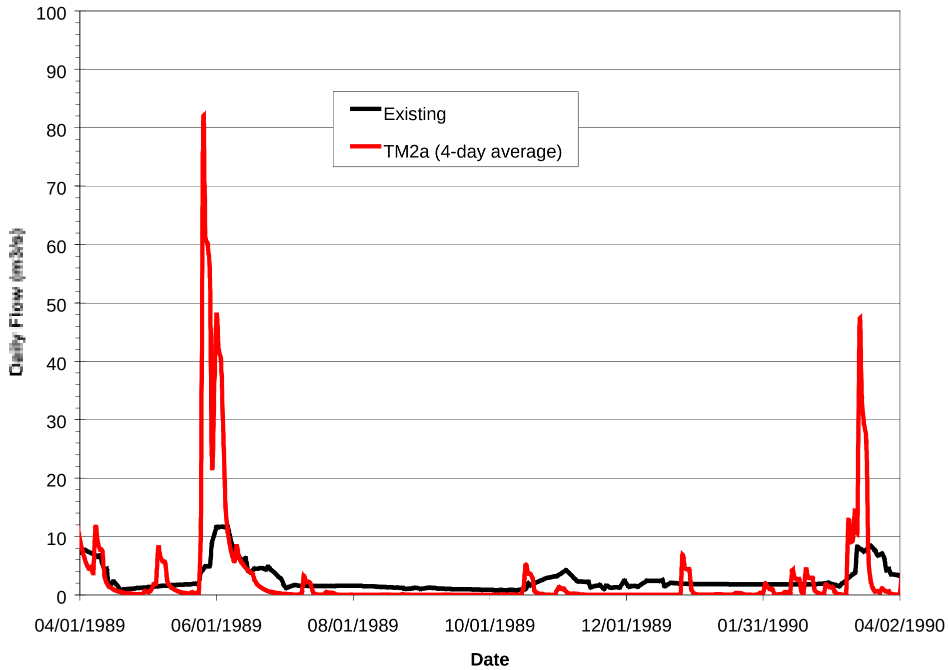

Figure 2—1. Comparison of Estimates for 1989-90 Period: Watershed Flows Upstream of the DePere Dam

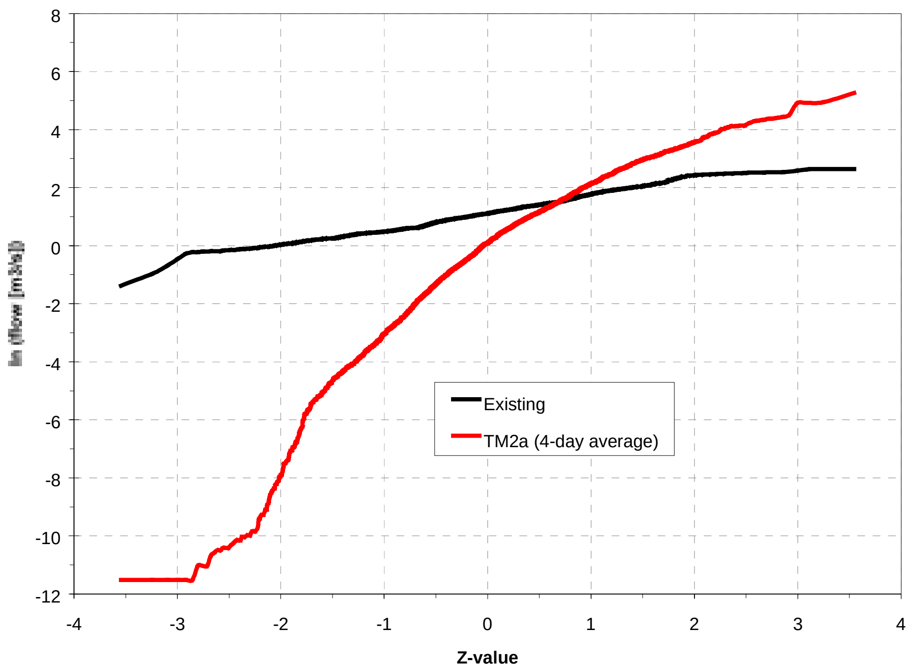

Figure 2—2. Comparison of Estimates for 1989-1995 Simulation Period: Distribution of Watershed Flows Upstream of the DePere Dam

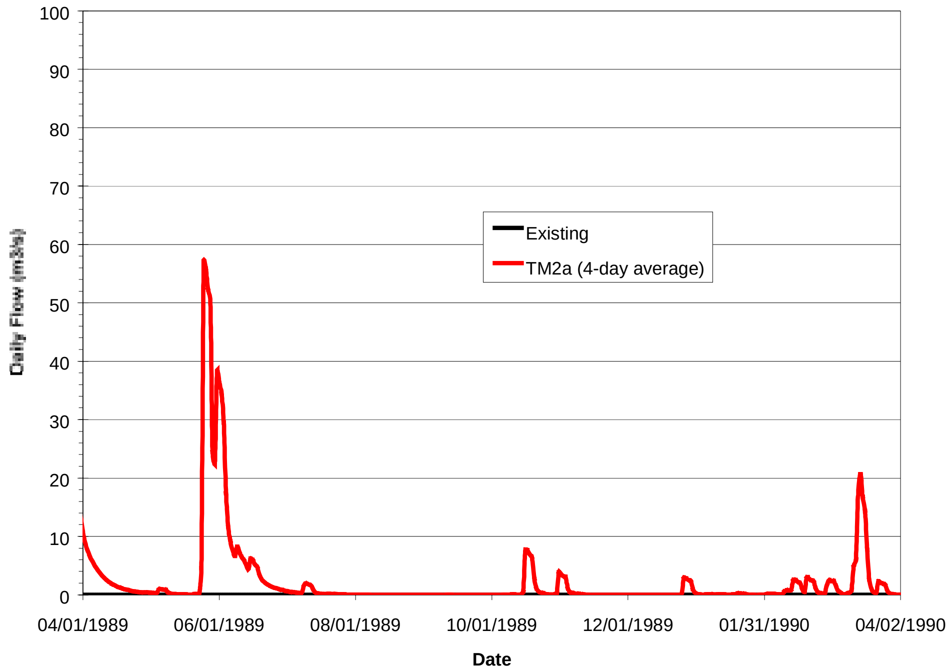

Figure 2—3. TM2a Estimates for 1989-90 Simulation Period: Watershed Flows Downstream of the DePere Dam

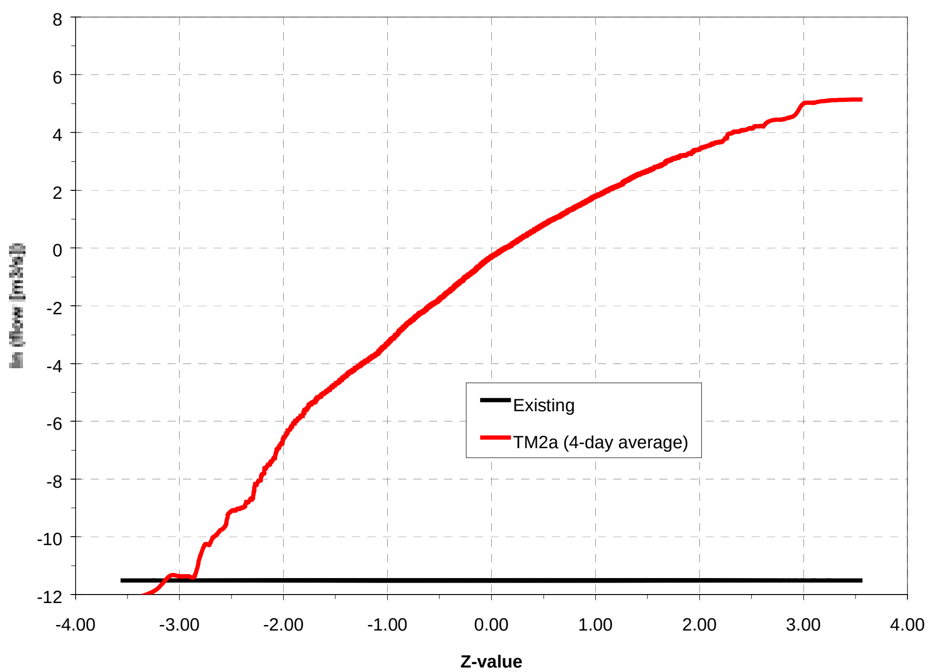

Figure 2—4. TM2a Estimates for 1989-95 Simulation Period: Distribution of Watershed Flows Downstream of the DePere Dam

Table 2-3 compares existing and TM2a daily watershed solids loads upstream of the DePere Dam for the 1989-95 simulation period. The maximum 4-day averaged TM2a daily solids load is considerably larger than the existing maximum load: 8,423,200 kg/day versus 966,238 kg/day. The mean TM2a load is also larger: 77,002 kg/day versus 8,566 kg/day. Despite the higher maximum and mean values, the median value of the TM2a loads is zero. This means that on at least half of the days the TM2a load estimate is zero (represented as a value of -11 on the y-axis) As presented in TM2a (FWB2000, 1998), the distribution of the TM2a loads is governed by rainfall. For periods when no rainfall occurred, TM2a load estimates are zero. These existing and TM2a solids loads for 1989-90 are presented in Figure 2-5. The TM2a loads exhibit large variability compared to the existing loads. Figure 2-6 compares the inverse log normal cumulative distribution functions of the values for 1989-95. Again, the majority of the TM2a loads are estimated to be zero with a median value of zero. The mean of the TM2a estimates is nonetheless considerably greater than the mean of the existing loads.

Table 2-4 compares existing and TM2a watershed daily solids downstream of the DePere Dam for the 1989-95 calibration period. The existing loads were input as a constant value of 17,700 kg/day. The solids loads for 1989-90 are presented in Figure 2-7. The TM2a loads exhibit similar variability to the TM2a flows. The maximum 4-day averaged TM2a load is considerably larger than the existing maximum load: 8,793,400 kg/day versus 17,700 kg/day. Figure 2-8 compares the inverse log normal cumulative distribution functions of the values for 1989-95. Like the loads for the river upstream of the DePere Dam, the majority of the TM2a daily solids loads are estimated to be zero. The mean of the TM2a loads is nonetheless considerably greater than the mean of the existing values. Watershed solids loads are important components of the overall mass balance of solids in the Lower Fox River between Lake Winnebago and the Green Bay. Because these loads have the potential to influence the results of short-term and long-term contaminant transport simulations, the 82% difference between the existing loads and those presented in TM2a is considered significant. Therefore, the Model Evaluation Workgroup recommends that the UFRM and LFRM be evaluated using the results of TM2a with 4-day averaging to define watershed solids inputs.

Watershed PCB loads were treated as zero in the UFRM and LFRM. The only nonpoint source of PCBs evaluated by the Workgroup under Task 2d was the Arrowhead Park landfill site. The average annual load from this source, solely attributable to particle runoff, was estimated to be 0 kg for 1989-1995. However, dissolved PCB concentrations in centrifuged groundwater samples collected from monitoring wells ranged from less than detectable to 1,981 ng/L. The dissolved PCB concentration in a sample from a monitoring well located in the containing dike wall of the landfill was 462 ng/L. Estimates of groundwater flow through the dike wall was range from 1,005 to 4,600 gallons/day (3.8 to 17.4 m^3/day). The groundwater PCB load estimate for Arrowhead Park was 0.035 g/day (0.013 kg/year) (Steuer et al. 1995).

Additional consideration was given to nonpoint source PCB loads based on predicted TM2a watershed flows and measured PCB concentrations in tributaries and stormwater. Analytical results for 7 PCB samples collected in 1976-77 by the WDNR from Ashwaubenon Creek were all non-detects. However, sediment residue samples obtained from 5 storm sewer catch basins

Table 2-3. Comparison of Estimates for 1989-95 Simulation Period: Watershed Solids upstream of the DePere Dam

Solids Summary	***Existing***	***TM2a***	***4-day averaged TM2a***
Minimum (kg/day)	5	0	0
Median (kg/day)	3673	0	0
Mean (kg/day)	8,566	77,002	77,002
Maximum (kg/day)	966,238	21,058,000	8,423,200

Table 2-4. Comparison of Estimates for 1989-95 Simulation Period: Watershed Solids downstream of the DePere Dam

Solids Summary	***Existing***	***TM2a***	***4-day averaged TM2a***
Minimum (kg/day)	17,700	0	0
Median (kg/day)	17,700	0	400
Mean (kg/day)	17,700	71,328	71,328
Maximum (kg/day)	17,700	20,738,000	8,793,400

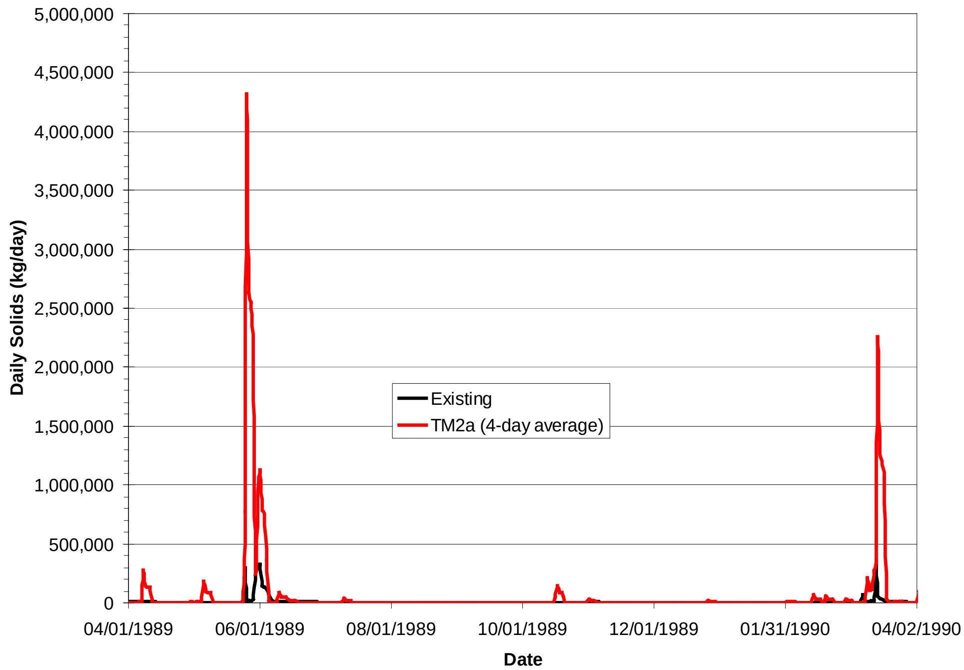

Figure 2—5. Comparison of Estimates for the 1989-90 Simulation Period: Watershed Solids Upstream of the DePere Dam

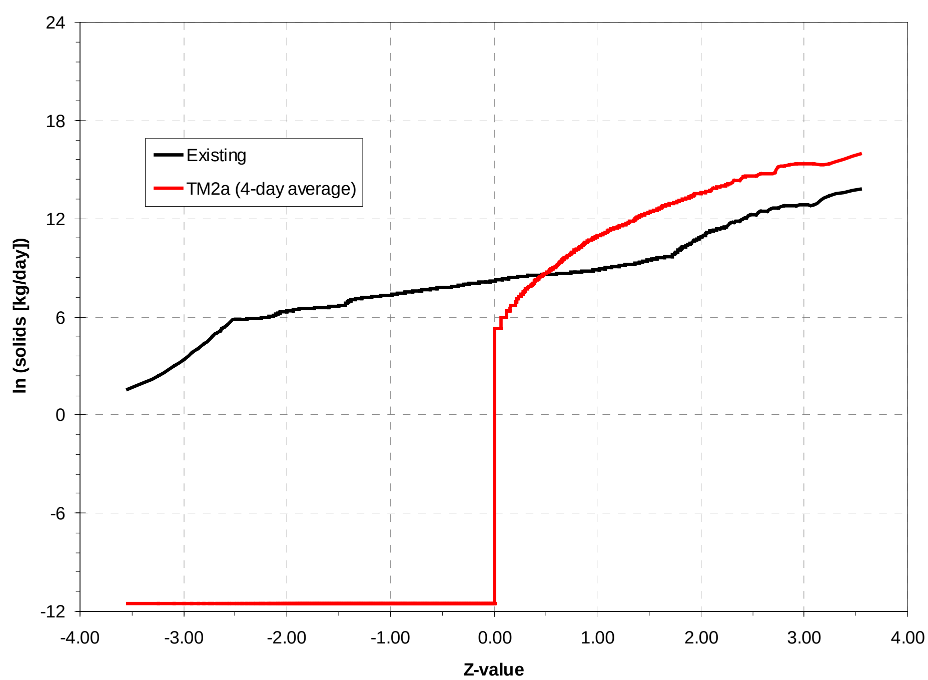

Figure 2—6. Comparison of Estimates for 1989-95 Simulation Period: Distribution of Watershed Solids Upstream of the DePere Dam

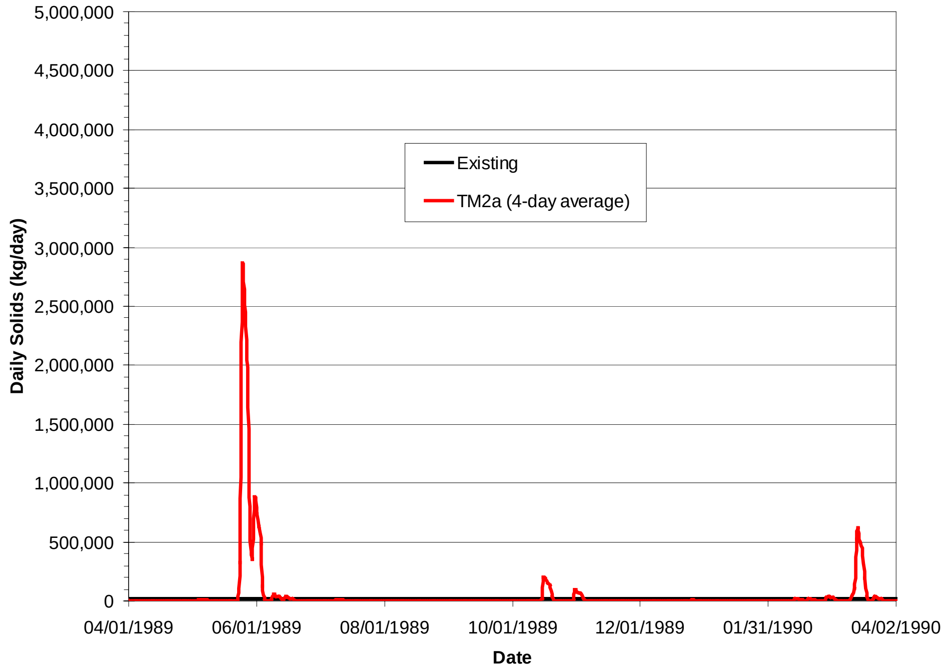

Figure 2—7. Comparison of Estimates for 1989-90 Period: Watershed Solids Downstream of the DePere Dam

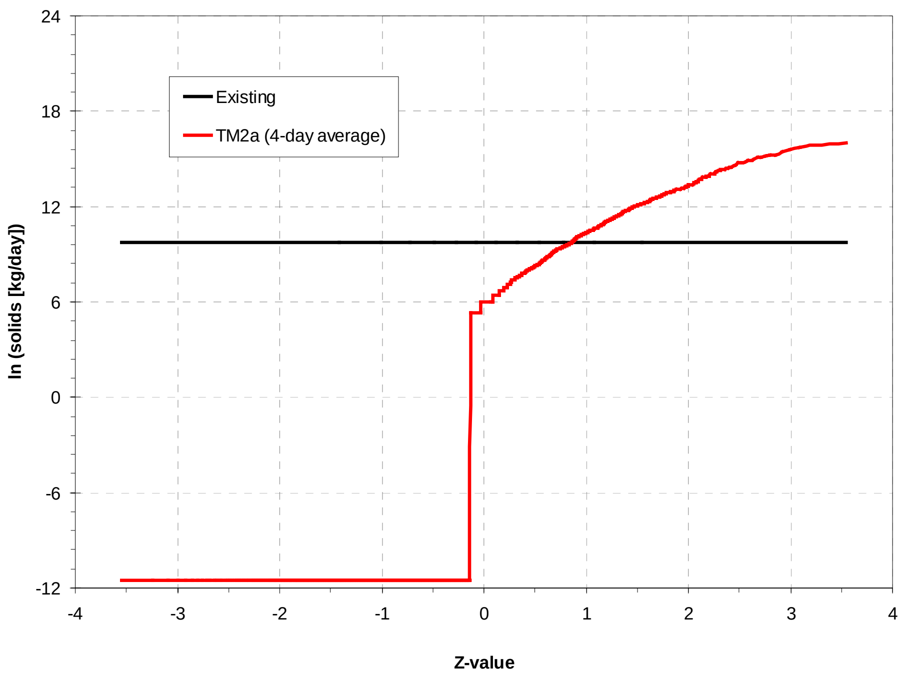

Figure 2—8. Comparison of Estimates for 1989-95 Simulation Period: Distribution of Watershed Solids Downstream of the DePere Dam

upstream of the DePere dam had a mean PCB concentration of 0.38 mg/kg. Sediment residue from 10 storm sewer basins downstream of the DePere dam had a mean PCB concentration of 0.15 mg/kg. Based on these sediment residue results, annual watershed PCB load estimates ranged from 0.57 to 2.13 kg/year for the UFRM area and 0.22 to 0.89 kg/year for the LFRM area (Steuer et al. 1995).

Similarly, PCBs were detected in 10% to 20% of samples collected during a study of four urban Wisconsin streams and 10 urban storm-sewer locations (Bannerman, 1996). In this study, the mean PCB concentration during events at the storm sewer sites was 110 ng/L.[2] This concentration, along with the estimate of watershed flow from urban areas in TM2a, was used to estimate nonpoint source PCB loads to the Lower Fox River. The TM2a watershed flow from urban areas was calculated on a subwatershed basis. The percent of urban area in each subwatershed and an adjustment to account for higher runoff rates in urban areas than rural areas were used to calculate the fraction of flow in each subwatershed from urban areas. The adjustment for higher runoff rates in urban areas was based on TM2a where surface runoff from urban areas was assumed to be from about 1.3 to 1.4 times the surface runoff simulated for rural areas (FWB2000, 1998). The adjustment applied in this calculation was 1.35. This approach yielded average load estimates of 4.4 kg/year for the river upstream of the DePere Dam and 2.9 kg/year downstream of the dam. Watershed PCB loads estimated in this manner are consistent with other load estimates presented in TM2a.

As PCBs are the primary focus of this model evaluation effort, any source of PCB was considered potentially important. Further, consistency between these load estimates and other TM2a loads estimates was also considered important. Therefore, the Model Evaluation Workgroup recommends that the UFRM and LFRM be evaluated with watershed PCB load estimates based on TM2a watershed flow estimates from urban areas and the measured PCB concentration of 110 ng/L in stormwater.

2.1.2 Point Source Flows and Loads

Point source flows, solids loads, and PCB loads to the Lower Fox River were previously estimated during development of the UFRM and the LFRM. Descriptions of the approaches used to estimate these model inputs cover several generations of model development. An overview of the procedures used to estimate UFRM point source inputs is presented by Steuer et al. (1995). Velleux (1992) presents an overview of the procedures used to estimate existing LFRM point source inputs.

In the existing models, point source flows and solids loads were estimated from Discharge Monitoring Reports (DMRs) provided by dischargers. Point source flows are very small (less than 5%) relative to the total stream flow and were treated as zero in both the UFRM and LFRM.

---

[2] It should be noted that the urban storm sewer PCB concentration data were collected from much larger and more heavily industrialized urban areas than the City of Green Bay or other urbanized regions of the Lower Fox River watershed. Therefore watershed PCB loads estimated from those data may represent an upper bound. It should be further noted that while the mean PCB concentration in the storm sewer samples was 110 ng/L, the median PCB concentration was less than detectable; PCBs were detectable in 20% or fewer of stream and storm sewer samples.

Each discharger reported point source solids loads. In the UFRM, solids loads for the 12 point sources believed to have the greatest potential for PCB discharges, listed in Table 2.5, were represented as constant values (the values do not change over time). In the LFRM, solids loads for the seven largest point sources believed to have the greatest potential for PCB discharges, also listed in Table 2-5, were represented as the reported daily solids load discharged.

Point source PCB loads were estimated from PCB observations collected as part of the Green Bay Mass Balance Study during 1989-90. These observations were used to compute an average PCB concentration associated with each discharger's effluent. A maximum likelihood estimator (MLE) procedure was used to estimate PCB concentrations for observed values that were less than the limit of detection for the sample (Dolan et al. 1993). Gross point source PCB loads were computed as the product of the daily point source flow and the average PCB concentration. These gross loads were then adjusted to account for PCBs present in influent water. The average observed PCB concentration in Lower Fox River surface water was used to represent influent conditions. The influent adjusted (net) point source PCB loads were represented in the UFRM and LFRM as average daily loads for the 19 dischargers listed in Table 2-5. These loads were treated as constants at the 1989-90 average value for the entire 1989-1995 simulation period.

To estimate point source inputs for the purpose of evaluating the existing models, point source flows, solids and PCB loads to the Lower Fox River between Lake Winnebago and Green Bay were examined in Task 2d. In this task, Discharge Monitoring Reports (DMRs), Cooperative Mill Surveys, production records, and other information (including confidential business information) provided directly by the dischargers were used to estimate point source inputs to the Lower Fox River for the period 1954-97. All permitted industrial and municipal wastewater dischargers were examined. These point source input estimates are presented in "Technical Memorandum 2d: Compilation and Estimation of Historical Discharges of Total Suspended Solids and Polychlorinated Biphenyls from Lower Fox River Point Sources" (TM2d) (WDNR, 1999a).

Summaries of annual point source flows and solids and PCB loads used in the existing models and the TM2d estimates are presented in Tables 2-5 through 2-9. The solids loads for the 1989-95 period are presented in Figures 2-9 and 2-10. The PCB loads for the 1989-95 period are presented in Figures 2-11 and 2-12. In TM2d, PCB loads for 5 specific dischargers were presented, and loads from all other dischargers were summed under the "All Other" discharge category. The TM2d solids loads are approximately 30% less than the existing loads during the 1989-1995 period.

Point source flows are small (4.3% of the total flow) relative to mainstem flows and are relatively constant. The Model Evaluation Workgroup recommends that these water inputs be treated as zero in the UFRM and LFRM.

Point source solids loads during the present era are very small relative to watershed solids loads and, in concept, could be treated as zero. However, for the long-term, historical simulation period, point source solids loads were estimated to be 10 to 50 times greater than contemporary

Table 2-5. Existing Model Point Source Solids Loads for the 1989-95 Simulation Period.

Model Segment	*Point Source*	*Avg Daily Solids Load (kg/day)*	*Annualized Solids Load (kg/yr)*
Lower Fox River Upstream of the DePere Dam		**5,108**	**1,864,420**
3	PH Glat, Kim Clark LV and BG	1,095	399,675
8	Grand Chute Neenah Menasha West STP	192	70,080
11	Appleton STP	1,248	455,520
13	Mid-Tech	679	247,835
15	Appleton Papers	333	121,545
16	Heart of the Valley STP/Thilmany Paper	1,561	569,765
Lower Fox River Downstream of the DePere Dam		**5,495**	**2,005,751**
1	International Paper, Nicolet Division	202	73,681
1	DePere STP	40	14,498
7	Fort Howard	2,055	749,958
13	P&G	458	167,020
14	GB Pack	174	63,452
15	James River	719	262,434
16	GBMSD	1,849	674,708

Table 2-6. TM2d Point Source Flows and Solids Loads Upstream of the DePere Dam for the 1989-95 Period

Existing Model Segment	Point Source	1989		1990		1991		1992		1993		1994		1995	
		Flow (m3/yr)	TSS (kg/yr)	Flow (m3/yr)	TSS (kg/yr)	Flow (m3/yr)	TSS (kg/yr)	Flow (m3/yr)	TSS (kg/yr)	Flow (m3/yr)	TSS (kg/yr)	Flow (m3/yr)	TSS (kg/yr)	Flow (m3/yr)	TSS (kg/yr)
Lower Fox River Upstream of the DePere Dam		**1.0E+8**	**1.9E+6**	**1.1E+8**	**2.3E+6**	**1.1E+8**	**2.3E+6**	**1.2E+8**	**1.8E+6**	**1.3E+8**	**1.8E+6**	**1.2E+8**	**1.6E+6**	**1.3E+8**	**1.9E+6**
2	American Tissue Mills	3.3E+6	1.0E+4	2.9E+6	7.1E+3	2.9E+6	7.5E+3	2.9E+6	8.0E+3	1.8E+6	4.2E+3	1.6E+6	4.8E+3	1.4E+6	4.7E+3
3	Kimberly Clark Corp.-Neenah/Badger Globe	4.8E+6	3.4E+4	4.7E+6	3.1E+4	4.6E+6	3.9E+4	5.0E+6	4.4E+4	4.9E+6	6.3E+4	5.1E+6	7.8E+4	5.1E+6	7.6E+4
3	P H Glatfelter Company	5.7E+6	1.2E+5	6.0E+6	2.7E+5	6.1E+6	2.5E+5	6.1E+6	2.8E+5	5.7E+6	2.2E+5	5.8E+6	2.3E+5	5.8E+6	3.5E+5
4	Neenah Menasha Sewerage Commission POTW	9.3E+6	3.1E+4	1.1E+7	5.7E+4	1.1E+7	5.7E+4	1.4E+7	8.3E+4	1.7E+7	1.1E+5	1.2E+7	5.2E+4	1.2E+7	6.1E+4
4	Menasha East POTW	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
4	American Can Canal Plant, Menasha	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
4	George Whiting Paper Corp.	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
4	Mead Corp., Gilbert Paper Division	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
4	U.S. Paper Mills Corp., Menasha Division	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
6	Wisconsin Tissue Mills	4.0E+6	1.5E+5	6.3E+6	3.4E+5	7.9E+6	2.7E+5	8.0E+6	1.9E+5	8.2E+6	1.4E+5	7.9E+6	1.8E+5	7.9E+6	1.0E+5
8	Grand Chute Menasha West POTW	4.3E+6	6.9E+4	5.2E+6	7.9E+4	5.5E+6	6.8E+4	6.4E+6	7.9E+4	7.3E+6	8.4E+4	6.2E+6	8.3E+4	6.9E+6	7.7E+4

Table 2-6 (continued). TM2d Point Source Flows and Solids Loads Upstream of the DePere Dam for the 1989-95 Period

Existing Model Segment	Point Source	1989		1990		1991		1992		1993		1994		1995	
		Flow (m3/yr)	TSS (kg/yr)	Flow (m3/yr)	TSS (kg/yr)	Flow (m3/yr)	TSS (kg/yr)	Flow (m3/yr)	TSS (kg/yr)	Flow (m3/yr)	TSS (kg/yr)	Flow (m3/yr)	TSS (kg/yr)	Flow (m3/yr)	TSS (kg/yr)
10	Riverside Paper Corp., Kerwin Division	1.8E+6	1.2E+5	8.4E+5	1.2E+5	8.4E+5	1.3E+5	1.1E+6	1.6E+5	9.2E+5	1.1E+5	7.1E+5	9.4E+4	6.2E+5	9.7E+4
11	Appleton POTW	1.6E+7	3.5E+5	1.8E+7	3.4E+5	1.8E+7	3.9E+5	2.0E+7	2.7E+5	2.2E+7	2.5E+5	2.0E+7	1.3E+5	2.2E+7	1.4E+5
11	Consolidated Paper, Appleton	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
13	Kimberly POTW	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
13	Consolidated Paper, Interlake Paper Inc.	1.7E+7	2.5E+5	1.6E+7	2.5E+5	1.6E+7	2.8E+5	1.6E+7	1.3E+5	1.7E+7	1.8E+5	1.7E+7	1.6E+5	1.8E+7	1.4E+5
15	Little Chute STP	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
15	Appleton Papers Inc., Locks Mill	7.6E+6	1.4E+5	7.7E+6	2.3E+5	7.3E+6	2.2E+5	7.5E+6	1.3E+5	7.7E+6	1.8E+5	1.0E+7	1.7E+5	1.2E+7	3.2E+5
16	HOV Metro Sewerage Dist/Kaukauna	5.1E+6	6.7E+4	6.5E+6	4.7E+4	6.9E+6	6.7E+4	7.4E+6	1.1E+5	8.5E+6	6.2E+4	7.0E+6	5.0E+4	7.3E+6	8.4E+4
16	International Paper Corp., Thilmany Division	2.3E+7	5.3E+5	2.6E+7	5.8E+5	2.5E+7	5.1E+5	2.4E+7	3.6E+5	2.6E+7	3.7E+5	2.9E+7	4.0E+5	2.6E+7	4.4E+5
18	Wrightstown Sewer & Water Utility	1.6E+5	1.1E+3	2.0E+5	7.5E+2	2.1E+5	7.1E+2	2.3E+5	8.6E+2	2.7E+5	1.3E+3	2.0E+5	1.1E+3	2.1E+5	1.1E+3
22	Charmin, Little Rapids Mill	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0

Table 2-7. TM2d Point Source Flows and Solids Loads Downstream of the DePere Dam for the 1989-95 Simulation Period

Existing Model Segment	*Point Source*	*1989*		*1990*		*1991*		*1992*		*1993*		*1994*		*1995*	
		Flow (m3/yr)	*TSS (kg/yr)*	*Flow (m3/yr)*	*TSS (kg/yr)*	*Flow (m3/yr)*	*TSS (kg/yr)*	*Flow (m3/yr)*	*TSS (kg/yr)*	*Flow (m3/yr)*	*TSS (kg/yr)*	*Flow (m3/yr)*	*TSS (kg/yr)*	*Flow (m3/yr)*	*TSS (kg/yr)*
Lower Fox River Downstream of the DePere Dam		**8.7E+7**	**2.0E+6**	**9.6E+7**	**1.8E+6**	**9.4E+7**	**1.6E+6**	**9.4E+7**	**1.5E+6**	**9.2E+7**	**1.3E+6**	**8.5E+7**	**1.2E+6**	**8.3E+7**	**1.3E+6**
1	DePere POTW	5.2E+6	1.5E+4	5.8E+6	1.1E+4	6.2E+6	9.3E+3	7.9E+6	1.4E+4	9.0E+6	4.2E+4	8.3E+6	4.7E+4	8.7E+6	2.0E+4
1	International Paper Corp., Nicolet Paper Division	3.2E+6	7.7E+4	3.9E+6	9.4E+4	3.7E+6	1.1E+5	3.5E+6	9.8E+4	3.7E+6	7.4E+4	3.6E+6	7.0E+4	3.4E+6	6.7E+4
1	U.S. Paper Mills Corp., DePere Division	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0	0.0E+0
7	Fort James Corp., Green Bay West Mill	1.9E+7	7.5E+5	2.2E+7	4.3E+5	2.3E+7	5.2E+5	2.1E+7	4.6E+5	1.7E+7	5.8E+5	1.4E+7	6.2E+5	1.4E+7	8.3E+5
13	Procter And Gamble Paper Products Company	6.0E+6	1.7E+5	5.1E+6	9.7E+4	4.4E+6	8.9E+4	4.2E+6	6.6E+4	6.8E+6	1.0E+5	7.0E+6	1.0E+5	6.8E+6	1.1E+5
14	Green Bay Packaging Inc.	2.6E+6	6.4E+4	2.8E+6	1.1E+5	2.4E+6	6.6E+4	2.3E+6	6.9E+4	2.4E+6	4.7E+4	2.3E+6	8.2E+4	1.9E+6	4.4E+4
15	Fort James Corp., Green Bay East Mill	1.2E+7	2.6E+5	1.0E+7	2.2E+5	1.1E+7	2.3E+5	1.1E+7	1.7E+5	1.1E+7	1.1E+5	1.1E+7	8.2E+4	1.1E+7	6.7E+4
16	Green Bay Metropolitan Sewerage District	3.9E+7	6.8E+5	4.7E+7	8.0E+5	4.3E+7	6.2E+5	4.4E+7	6.0E+5	4.2E+7	3.2E+5	3.9E+7	1.9E+5	3.7E+7	1.2E+5

Table 2-8. Existing Model Point Source PCB Loads for 1989-95 Simulation Period

Existing Model Segment	***Point Source***	***PCB Load (kg/yr)***
Lower Fox River Upstream of the DePere Dam		**0.56**
3	P. H. Glatfelter, Kimberly-Clark Lake View and Badger Globe	0.24
4	Neenah-Menasha STP	0.03
6	Wisconsin Tissue	0.12
8	Grand Chute/Menasha West STP	0.01
10	Riverside Paper	0.02
11	Appleton STP	0.09
13	Interlake Paper (Consolidated Paper)	0.00
15	Appleton Papers Locks Mill	0.02
16	Heart of the Valley STP	0.03
16	Thilmany Paper	0.00
Lower Fox River Downstream of the DePere Dam		**3.13**
1	International Paper, Nicolet Division	0.01
1	DePere STP	0.24
7	Fort James West	0.96
13	Proctor & Gamble	0.12
14	GB Packaging	0.06
15	Fort James East	0.36
16	GBMSD	1.38

Table 2-9. TM2d Point Source PCB Loads for 1989-95 Simulation Period

Existing Model Segment	*Point Source*	*PCB Load (kg/yr)*						
		1989	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*
Lower Fox River Upstream of the DePere Dam		**1.91**	**3.08**	**2.49**	**1.86**	**1.63**	**1.36**	**1.95**
3	PH Glatfelter	0.86	1.63	1.27	1.27	0.86	0.77	1.00
4	Neenah/Menasha POTW	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Appleton POTW	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Appleton Paper-Locks Mill	1.04	1.45	1.22	0.59	0.77	0.59	0.95
Lower Fox River Downstream of the DePere Dam		**19.50**	**9.62**	**10.16**	**7.57**	**8.26**	**7.62**	**8.75**
7	Fort James West	19.50	9.62	10.16	7.57	8.26	7.62	8.75
Lower Fox River Miscellaneous								
	Total of all others	2.04	2.27	1.77	1.41	1.09	0.95	0.73

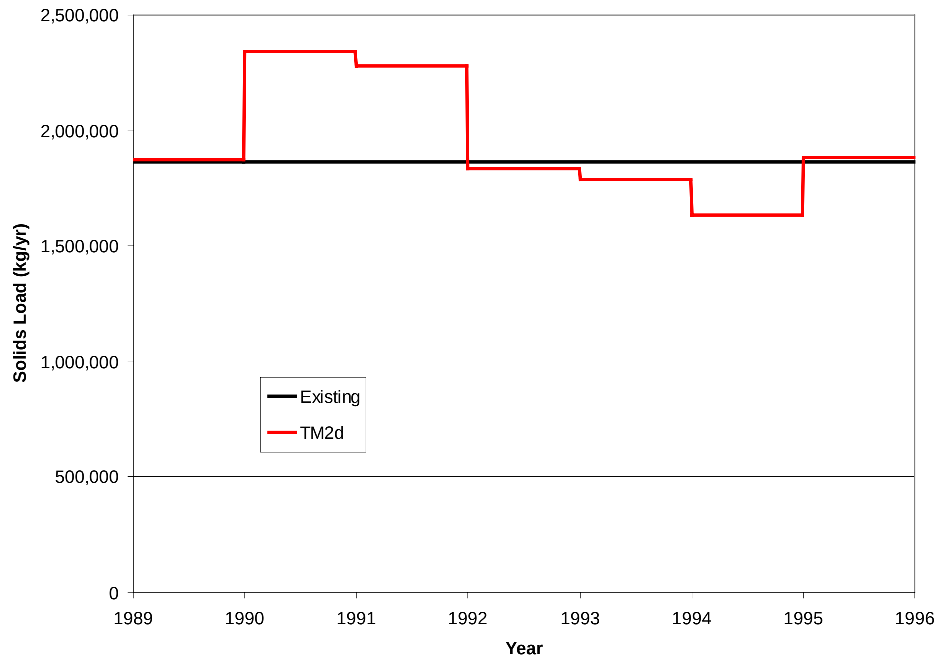

Figure 2—9. Comparison of Estimates for 1989-95 Simulation Period: Point Source Solids Upstream of the DePere Dam

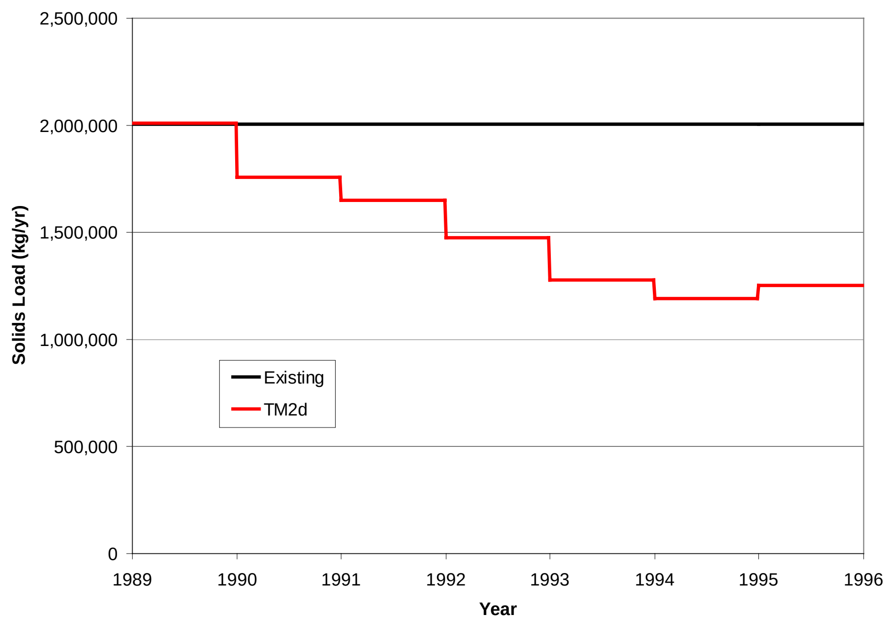

Figure 2—10. Comparison of Estimates for 1989-95 Simulation Period: Point Source Solids Downstream of the DePere Dam

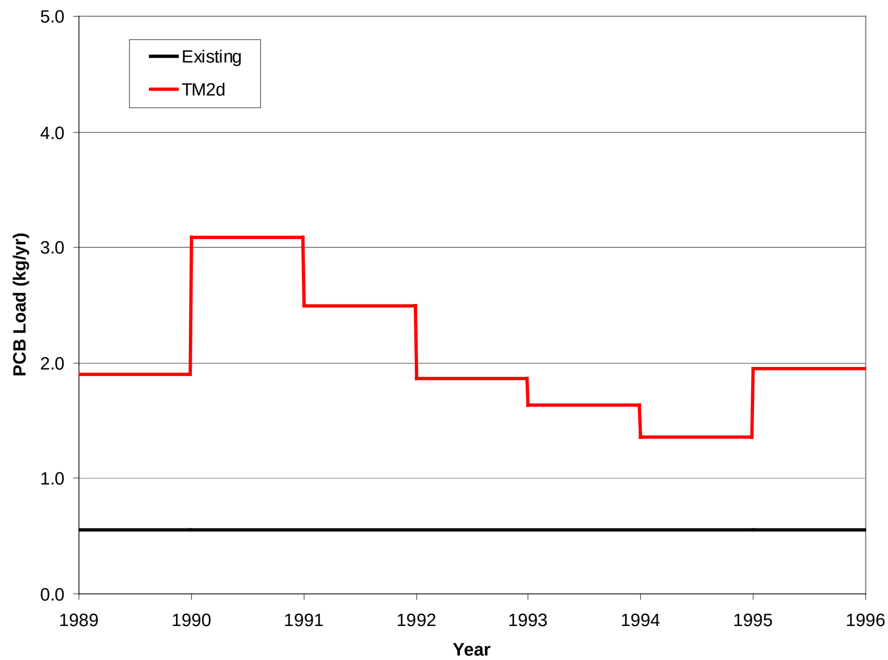

Figure 2—11 Point Source PCB Loads Upstream of the DePere Dam

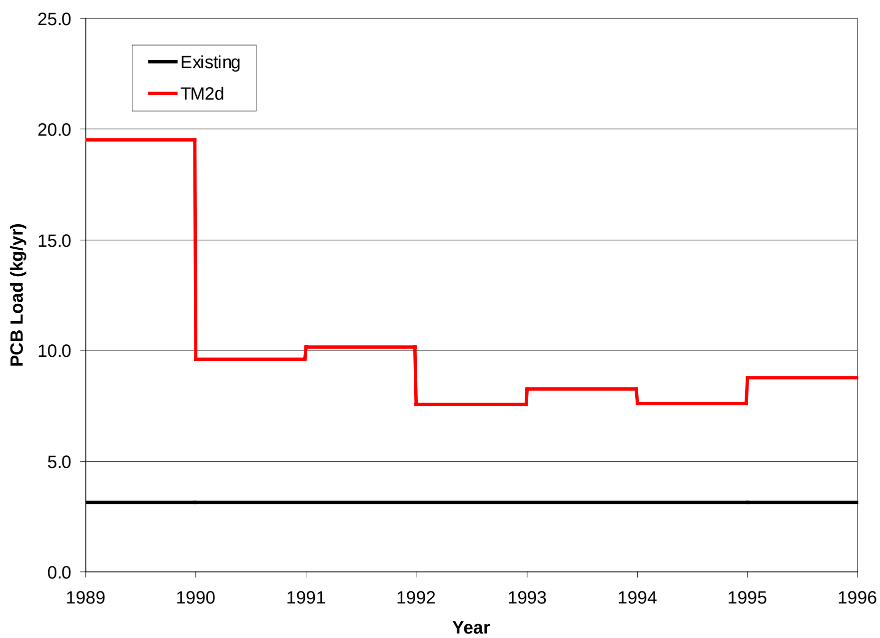

Figure 2—12. Point Source PCB Loads Downstream of the DePere Dam

values. Under historical conditions, point source solids loads represented an appreciable component (~30%) of the total solids load to the river especially during low flow, dry weather periods. Because these loads have the potential to influence the results of short-term and long-term contaminant transport simulations, the difference between the existing loads and those presented in TM2d is considered significant. In consideration of this, as well as the desire for consistency in model applications for short-term and long-term simulations, the Model Evaluation Workgroup recommends that point source solids loads be represented in the UFRM and LFRM as estimated in TM2d (monthly average values).

PCB loads are key features of model simulations. For short-term simulation, point source PCB inputs are expected to be very small relative to PCB inputs from the sediments. However small, point source PCB inputs are nonetheless non-zero during the 1989-1995 period (based on 1989-90 observations). Regardless of magnitude, these loads represent an external source of PCBs to the system and are therefore considered significant. Since point source PCB loads are the key PCB input to the system during the long-term simulation period (beginning in 1954), these loads are considered significant for long-term simulations. The Model Evaluation Workgroup recommends that point source PCB loads be represented in the UFRM and LFRM as estimated in TM2d (annual average values).

2.1.3 Internal Production

Internal production represents the growth of biotic solids (such as plankton and zooplankton) in the water column in response to temperature, light, and nutrients. Biotic solids are an important component of the overall solids balance of the Lower Fox River. The internal solids loads of the Lower Fox River were previously estimated during development of the UFRM and the LFRM. Different approaches were used to estimate these loads in each existing model. An overview of the procedures used to estimate UFRM internal solids loads is presented by Steuer et al. (1995). An overview of procedures to estimate LFRM internal solids loads is presented by Velleux (1992).

<u>Lower Fox River Upstream of the DePere Dam</u>

The existing UFRM employs a net biotic solids loading approach in which loads were computed as the difference between downstream and upstream water column fluxes. Using this approach, internal solids loads were computed at five locations between Lake Winnebago and the DePere Dam. A regression estimator was used to compute in-stream chlorophyll-a concentrations as a function of river flow and water temperature. Gross internal loads were computed as the product of observed flow and the predicted chlorophyll-a concentrations. Net biotic loads were then computed as the difference of gross loads between any two adjacent locations.

To estimate internal solids load inputs for the purpose of evaluating the existing UFRM, data related to algal growth in the Lower Fox River between Lake Winnebago and Green Bay were examined in Task 2c. In this task, Secchi disk depth (which described the depth to which light penetrates the water column), water temperature, nutrients (phosphorus), and chlorophyll-a data were used to estimate biotic solids inputs to the Lower Fox River for the period 1954-1995. These load estimates were computed using a simplified primary production (SPP) approach.

These internal load estimates are presented in “Technical Memorandum 2c: Computation of Internal Solids Loads in Green Bay and the Lower Fox River” (TM2c) (LTI, 1999b).

Table 2-10 presents internal solids load estimates for the 1989-1995 simulation period. Figure 2-13 is a graphical presentation of the 1989-90 internal solids loads. The loads estimated using the existing method are more variable than the loads estimated using the TM2c SPP approach. The SPP approach estimates considerably higher internal solids production during the summer months than the existing approach (about twice as high). A comparison of the inverse log normal cumulative distribution functions of the daily estimates for the 1989-95 period is shown in Figure 2-14. In general, the distribution of TM2c loads is similar to the existing loads. The mean values of the distributions differ by less than about 27%. The most notable differences occur in the lower half of the distribution. This difference is the result of zero values in the existing load estimates. The overall temporal distributions of the load estimates are also quite different. Internal solids loads are an important component of the overall mass balance of solids in the Lower Fox River between Lake Winnebago and the DePere Dam. Because these loads have the potential to influence the results of short-term and long-term contaminant transport simulations, the 27% difference between the existing loads and those presented in TM2c is considered significant. Therefore, the Model Evaluation Workgroup recommends that the UFRM be evaluated using the results of TM2c to define internal solids inputs.

Table 2-10. Comparison of Estimates for the 1989-95 Simulation Period: Internal Solids Upstream of the DePere Dam

Year	***Existing Approach (net solids) (kg/yr)***	***TM2c SPP Approach (gross solids) (kg/yr)***
1989	14,177,867	14,089,976
1990	13,065,079	15,191,673
1991	9,780,550	14,714,977
1992	10,818,055	18,744,843
1993	10,810,895	18,744,843
1994	10,099,818	17,243,522
1995	9,182,326	7,911,646

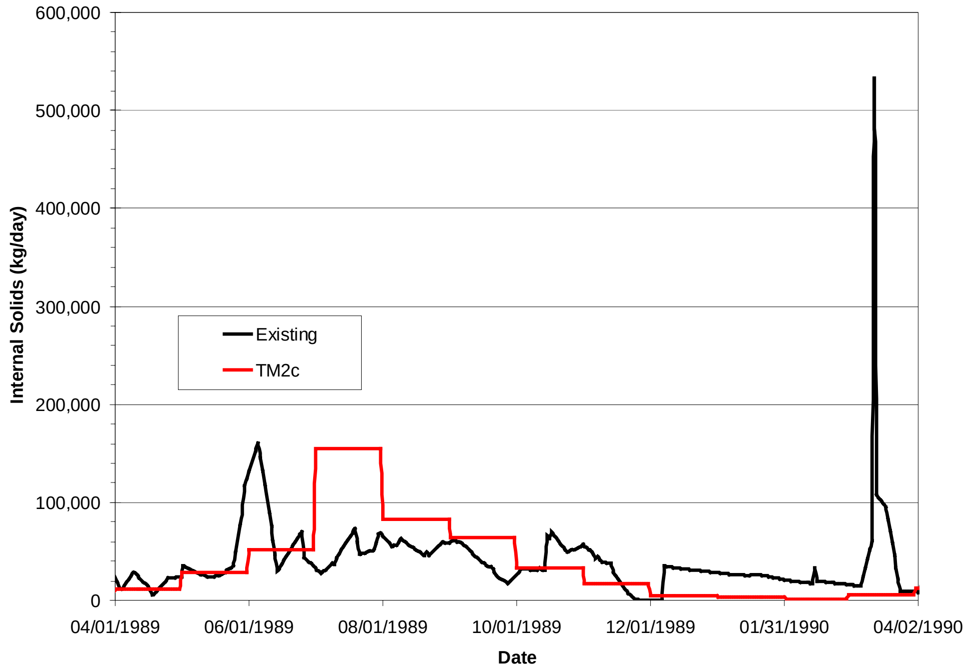

Figure 2—13. Comparison of Estimates for 1989-90 Study Period: Internal Solids upstream of the DePere Dam

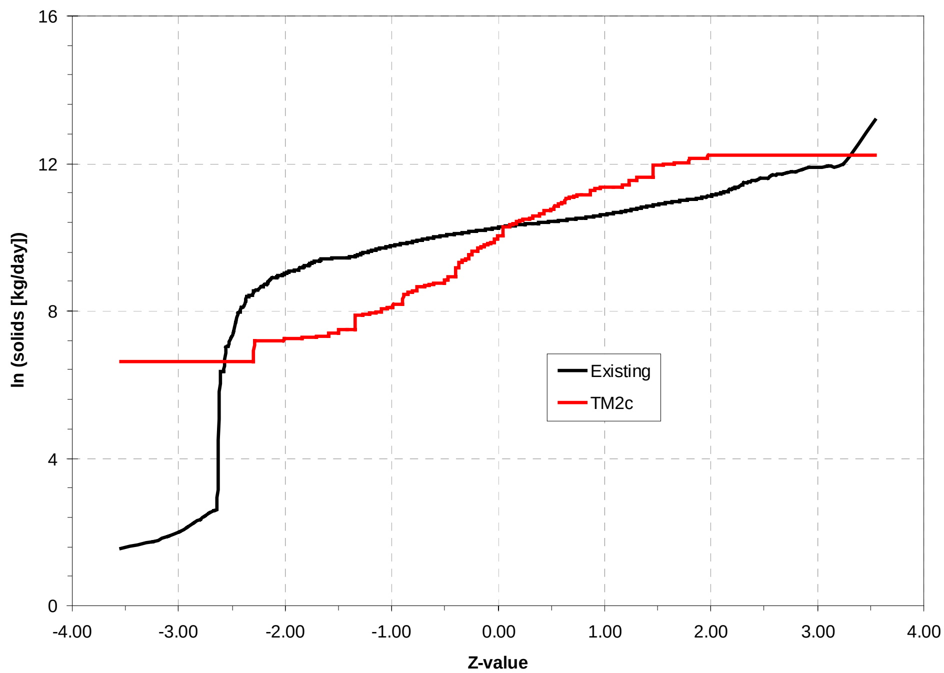

Figure 2—14. Comparison of Estimates for 1989-95 Simulation Period: Distribution of Internal Solids Upstream of the DePere Dam

Lower Fox River between the DePere Dam and Green Bay

The existing LFRM employs a gross biotic solids loading approach. Loads were computed from historical productivity data collected near the river mouth (inner Green Bay) in the early 1980s and light extinction data from the inner bay in 1980, using the relationship between biotic solids and chlorophyll-a described by Raghunathan (1990). The gross internal solids loads computed from this method depend only on the time series of productivity and light extinction and are independent of river flow. The total annual load computed was 4.63 million kg/yr. Since this estimate does not depend on flow, the annual load times series was repeated for each year of a simulation.

To estimate internal solids load estimates for the purpose of evaluating the existing LFRM, data related to algal growth in the Lower Fox River between Lake Winnebago and Green Bay were examined in Task 2c. In this task, Secchi disk depth (which described the depth to which light penetrates the water column), water temperature, nutrients (phosphorus), and chlorophyll-a data were used to estimate biotic solids inputs to the Lower Fox River for the period 1954-1995. These load estimates were computed using a simplified primary production (SPP) approach. This is the same approach used for the UFRM. The internal load estimates are presented the results in TM2c (LTI, 1999b).

Table 2-11 presents internal solids loads estimates for the 1989-1995 simulation period. Figure 2-15 is a graphical presentation of internal solids loads for the 1989-90 period. The TM2c SPP load estimate is higher for the period May-July and lower for the period August-November. A comparison of the inverse log normal cumulative distribution functions for the 1989-95 period of the daily estimates is shown in Figure 2-16. In general, the load estimates are similar. The mean values of the distributions differ by less than 5%. The most notable differences occur in the lower half of the distribution. This difference is the result of zero values in the existing load estimates. The overall seasonal distributions of the load estimates are quite similar, but the year-to-year trends are significantly different. Internal solids loads are an important component of the overall mass balance of solids in the Lower Fox River between the DePere Dam and Green Bay. Because these loads have the potential to influence the results of short-term and long-term contaminant transport simulations, the year-to-year differences between the existing loads and those presented in TM2c are considered significant. Therefore, the Model Evaluation Workgroup recommends that the LFRM be evaluated using the results of TM2c to define internal solids inputs.

Table 2-11. Comparison of Estimates for 1989-95 Simulation Period: Internal Solids downstream of the DePere Dam

Year	*Existing Approach (kg/yr)*	*TM2c SPP Approach (kg/yr)*
1989	4,629,504	4,466,804
1990	4,629,504	4,788,693
1991	4,629,504	4,649,414
1992	4,629,504	5,765,475
1993	4,629,504	5,765,475
1994	4,629,504	5,388,194
1995	4,629,504	2,661,646

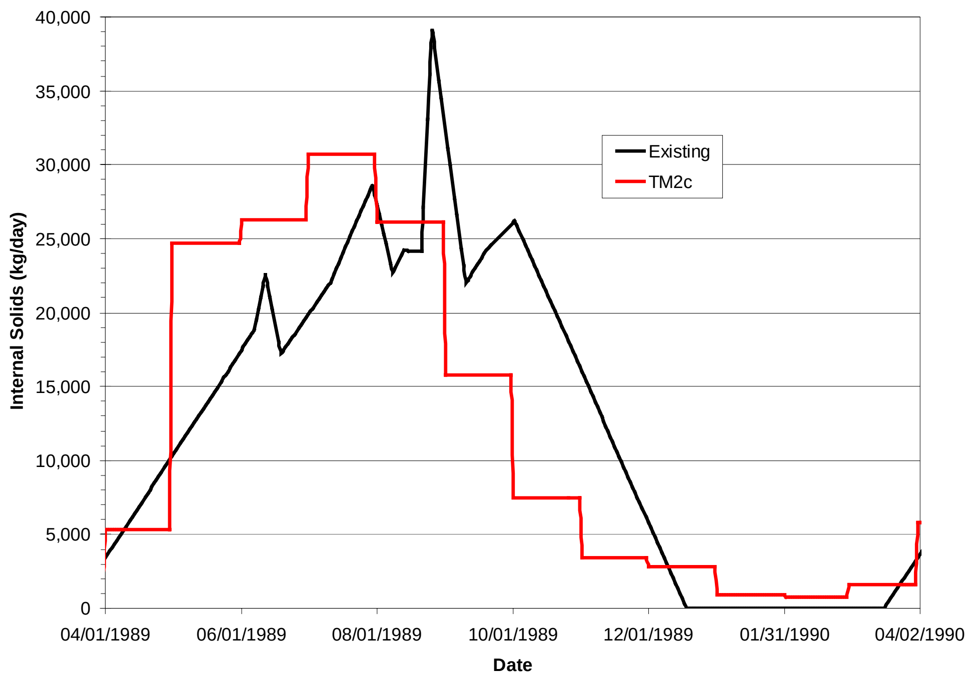

Figure 2—15. Comparison of Estimates for 1989-90 Period: Internal Solids Downstream of the DePere Dam

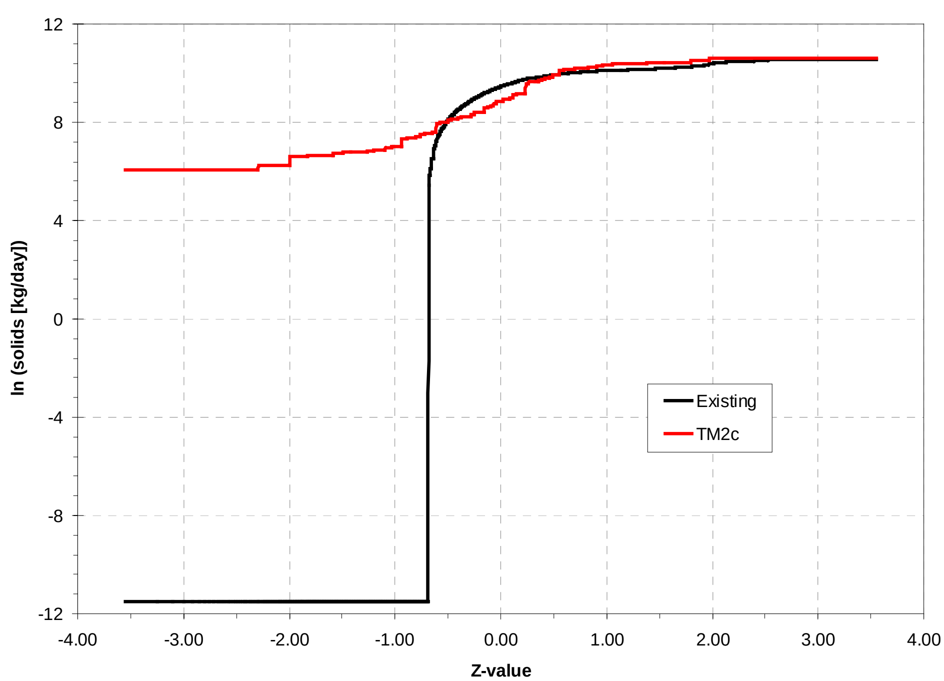

Figure 2—16. Comparison of Estimates for 1989-95 Simulation Period: Distribution of Internal Solids Downstream of the DePere Dam

2.2 GREEN BAY

2.2.1 Watershed Flows and Loads

Watershed flows, solids loads, and PCB loads to Green Bay were estimated during development of GBTOX (Bierman et. al., 1992). The existing estimates were developed for the four major tributaries to Green Bay, excluding the Lower Fox River. These four tributaries were the Menominee, Oconto, Peshtigo, and Escanaba Rivers. Except for the Escanaba River, watershed flows were determined from daily flow observations. Flows from the Escanaba River were not included in GBTOX. The daily flows and less frequent suspended solids and PCB concentration data were available for 1989-1990. This information was used to develop regression estimators of solids and PCB concentrations as functions of flow. The flow observations and regression estimators were then used to estimate watershed solids and PCB loads.

To estimate watershed inputs for the purpose of evaluating the existing GBTOX model, watershed flows, solids and PCB loads to Green Bay were examined in Task 2b. In this task, stream flow, suspended solids and PCB measurements, shoreline recession information, land use, and watershed area were used to estimate watershed inputs to Green Bay for the period 1954-1995. There are three groups of Green Bay watershed areas: monitored, unmonitored, and direct drainage. The monitored tributaries are the Peshtigo, Oconto, Menominee, Escanaba, and Ford Rivers. The unmonitored tributaries are Duck Creek and the Pensaukee, Cedar, Fishdam, Rapid, Sturgeon, Tacoosh, and Whitefish Rivers. Direct drainage areas are watershed areas that include very small streams or runoff that drains directly to Green Bay. Flows for monitored tributaries were determined directly from observations. Flows for unmonitored tributaries and direct drainage areas were based on flows for the Ford River and drainage area ratios. Beale's Unstratified Ratio Estimator (BURE) was applied to estimate watershed solids loads for the monitored tributaries based on flow and suspended solids observations. Solids loads for the unmonitored tributaries and direct drainage areas were based on estimated loads for the Ford River and drainage area ratios. PCB loads were based on watershed delivery rates and inferred PCB deposition rates in peat cores. These watershed input estimates are presented in Technical Memorandum 2b: Computation of Watershed Solids and PCB Load Estimates for Green Bay" (TM2b) (LTI, 1999a).

Table 2-12 presents existing and TM2b watershed flow estimates for the 1989-90 and 1989-95 periods, respectively. The flows are presented graphically in Figure 2-17. On average, the TM2b flows are approximately double the existing flows. The maximum TM2b flows are 3 times higher than the maximum existing flows. The comparison of the inverse log normal cumulative distribution functions of these values for 1989-90 is shown in Figure 2-18. The existing and TM2b watershed flows have similar distributions but theTM2b flows are approximately double the existing flows.

Watershed flows are an important component of the overall water balance for Green Bay. The nearly 50% relative difference between the existing and TM2b flow estimates is considered significant. In comparison to the combined inflow of the Lower Fox River, watershed flows are significant (1.5 times greater). Therefore the Model Evaluation Workgroup recommends that the GBTOX be evaluated using watershed flows as represented in TM2b.

Table 2-12. Comparison of Estimates for 1989-95 Simulation Period: Green Bay Watershed Flows

Watershed Flow Summary	***Existing***	***TM2b***	
	1/1/89-6/1/90	***1/1/89-6/1/90***	***1/1/89-12/31/95***
Minimum (m3/s)	43	63	63
Median (m3/s)	78	124	163
Mean (m3/s)	111	199	226
Maximum (m3/s)	433	1,042	1,434

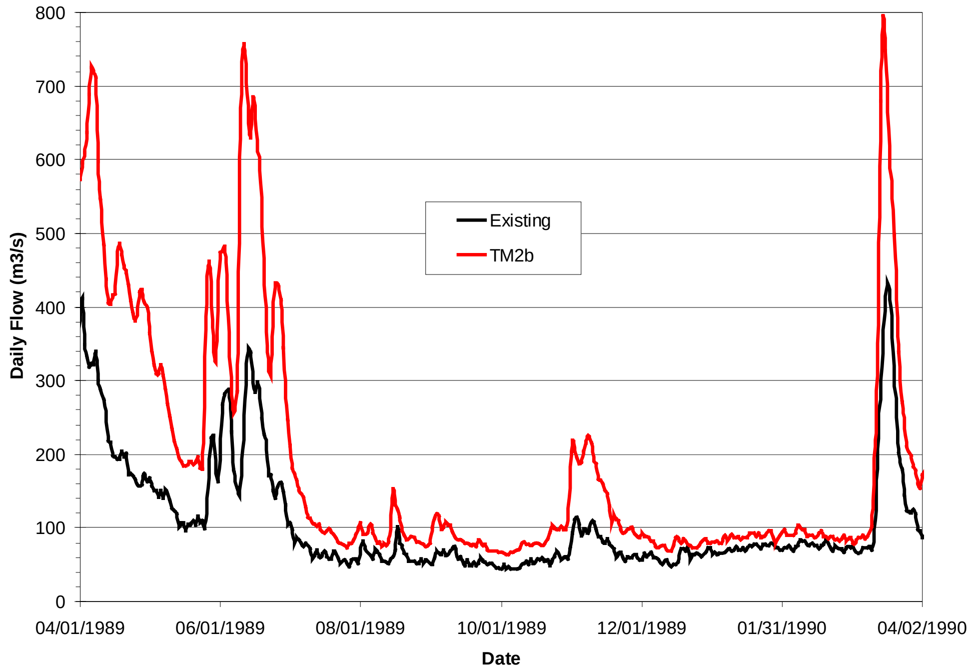

Figure 2—17. Comparison of Estimates for 1989-90 Period: Green Bay Watershed Flows

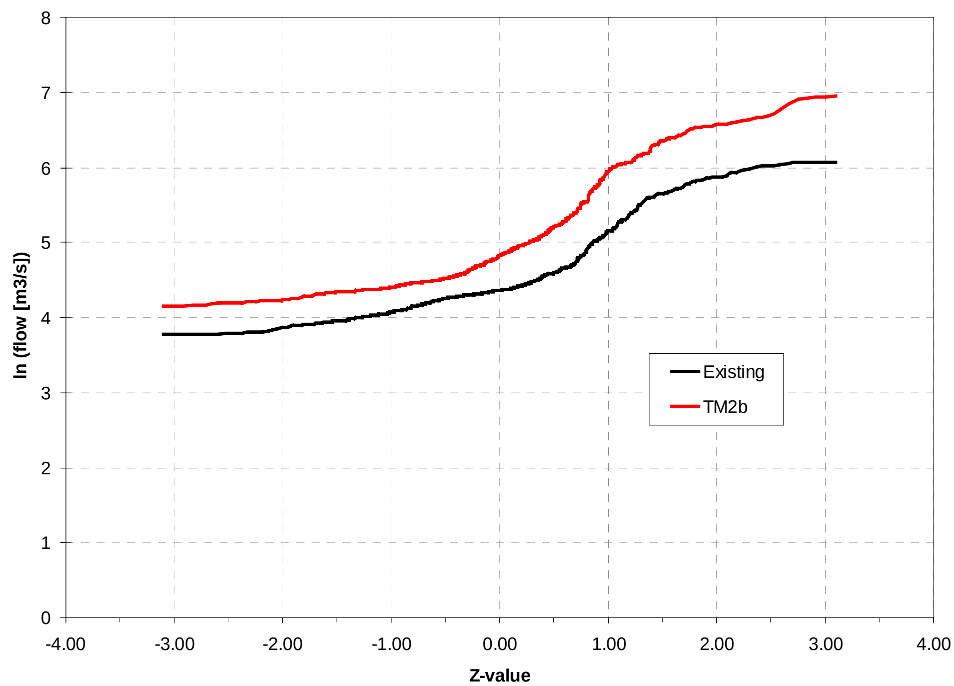

Figure 2—18. Comparison of Estimates for 1/1/89 – 6/1/90 Simulation Period: Distribution of Green Bay Watershed Flows

Table 2-13 compares existing and TM2b watershed solids load estimates for the 1989-90 and 1989-95 periods, respectively. The loads for the 1989-90 period are compared graphically in Figure 2-19. On average, the TM2b solids loads are approximately three times larger than the existing loads. The maximum TM2b solids loads are considerably (5 times) higher than the maximum value of the existing solids. The comparison of the inverse log normal cumulative distribution functions of the values for the 1989-90 period are shown in Figure 2-20. The two lines indicate that the existing and TM2b watershed loads have the same general distribution but that theTM2b loads are approximately 2-3 times greater than the existing loads.

Watershed solids loads are an important component of the overall mass balance of solids in Green Bay. Because these loads have the potential to influence the results of short-term and long-term contaminant transport simulations, the large difference between the existing loads and those presented in TM2b is considered significant. Therefore, the Model Evaluation Workgroup recommends that GBTOX be evaluated using the representation of watershed solids presented in TM2b.

As noted in TM2b, shoreline erosion may also be a major component of the total solids balance in Green Bay. In the existing GBTOX, shoreline erosion loads were treated as zero. Shoreline erosion solids loads may be much larger (six times larger or more) than the estimated loading from non-Lower Fox tributaries to Green Bay and of similar magnitude to internal solids loads (about 380,000 metric tons versus about 240,000 metric tons). The Model Evaluation Workgroup further recommends that GBTOX (specifically the GBTS total suspended solids submodel) be evaluated using a representation of solids loads from shoreline erosion developed from the information presented in TM2b.

Table 2-13. Comparison of Estimates for 1989-90 and 1989-95 Simulation Periods: Green Bay Watershed Solids

Watershed Solids Summary	***Existing***	***TM2b***	
	1/1/89-6/1/90	***1/1/89-6/1/90***	***1/1/89-12/31/95***
Minimum (kg/day)	3,438	9,637	9,637
Median (kg/day)	10,808	19,875	26,623
Mean (kg/day)	14,822	38,130	40,739
Maximum (kg/day)	57,680	237,561	301,218

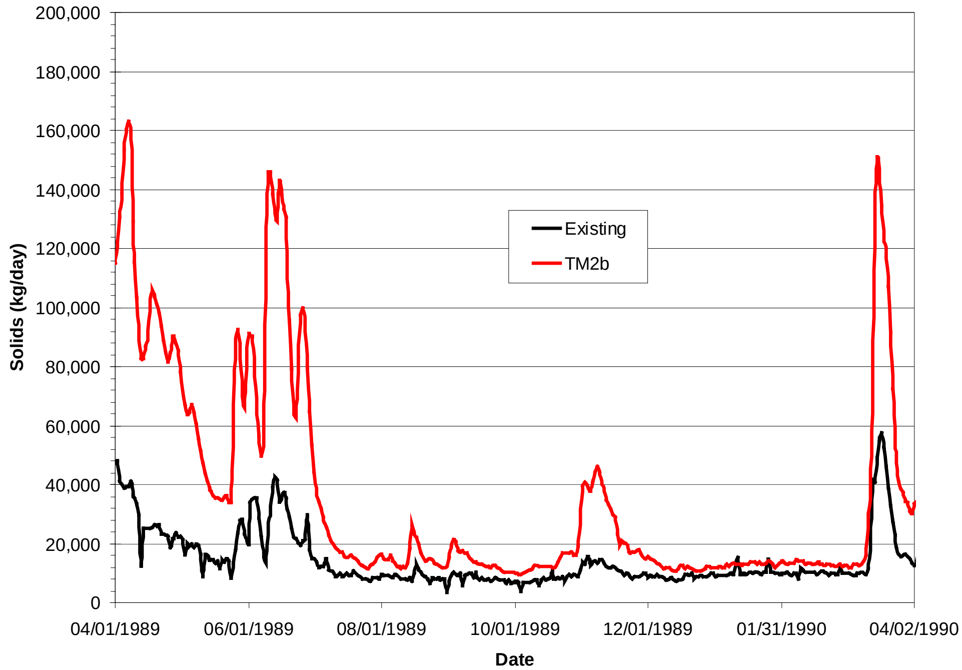

Figure 2—19. Comparison of Estimates for 1989-90 Period: Green Bay Watershed Solids

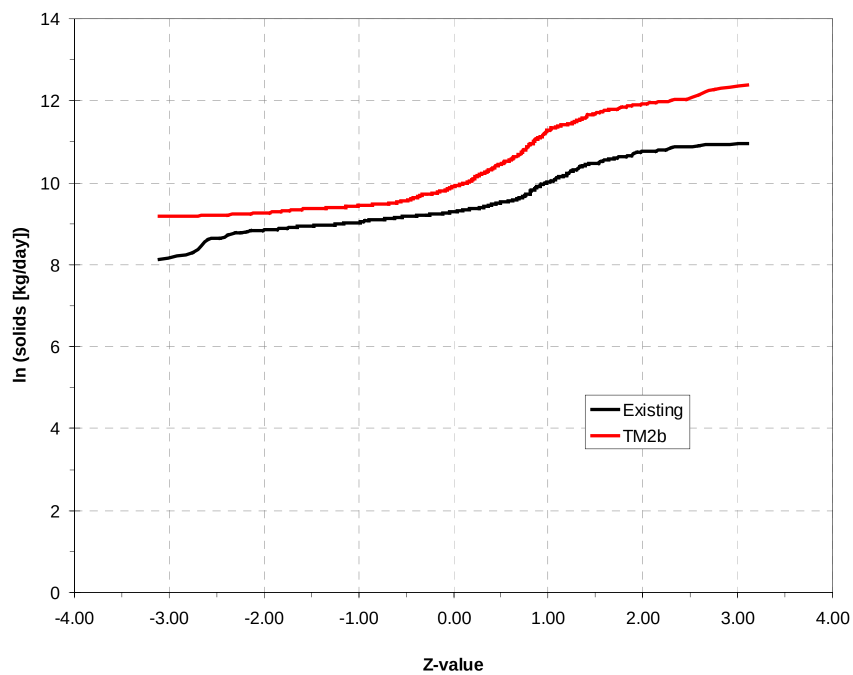

Figure 2—20. Comparison of Estimates for 1/1/89 – 6/1/90 Simulation Period: Distribution of Green Bay Watershed Solids

Table 2-14 compares existing and TM2b watershed PCB loads for the 1989-90 and 1989-95 periods, respectively. Figure 2-21 shows a graphical comparison of the TM2b watershed PCB loads for the 1989-90 period. On average, during 1989-1990, the TM2b watershed PCB loads are greater than the existing loads. The inverse log normal cumulative distribution functions of the values for the 1989-90 period are shown in Figure 2-22. The existing and TM2b watershed PCB load estimates have similar distributions. The TM2b load estimates are greater for throughout most of the distribution and 30% greater at the mean value (comparing 1989-1990). However, the existing loads are greater at the higher end of the distribution.

PCB loads are key features of model simulations. As represented in the existing model, watershed PCB inputs are expected to be small (<1%) relative to PCB inputs from the Lower Fox River or Green Bay sediments. The TM2b results, although greater than the existing load estimates for 1989-1990, suggest that the potential contributions of Green Bay watershed PCBs to the overall mass balance of PCBs are nonetheless expected to be small (<1%) relative to other sources. However small, estimated watershed PCB inputs to Green Bay are nonetheless non-zero. Regardless of magnitude, these loads represent an external source of PCBs to the system and are therefore considered significant. The 30% relative difference between the TM2b and existing load estimates are large (comparing 1989-1990). While this is a small load compared to other sources, and small difference between existing and TM2b loads, any source or difference in estimates of PCBs is considered potentially important. The Model Evaluation Workgroup therefore recommends that watershed PCB loads be represented in GBTOX as estimated in TM2b.

Table 2-14. Comparison of Estimates for 1989-90 and 1989-95 Periods: Green Bay Watershed PCBs

Watershed PCB Summary	***Existing***	***TM2b***	
	1/1/89-6/1/90	***1/1/89-6/1/90***	***1/1/89-12/31/95***
Minimum (kg/d)	0.009	0.016	0.007
Median (kg/d)	0.021	0.034	0.025
Mean (kg/d)	0.044	0.060	0.038
Maximum (kg/d)	0.428	0.324	0.324

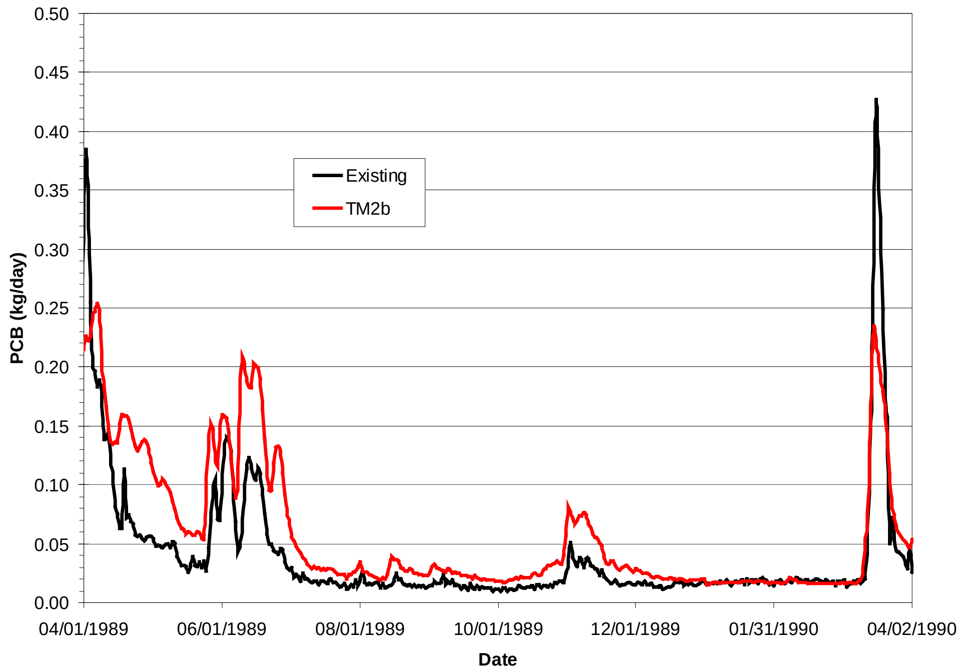

Figure 2—21. Comparison of Estimates for 4/1/89 - 3/31/90 Period: Green Bay Watershed PCBs

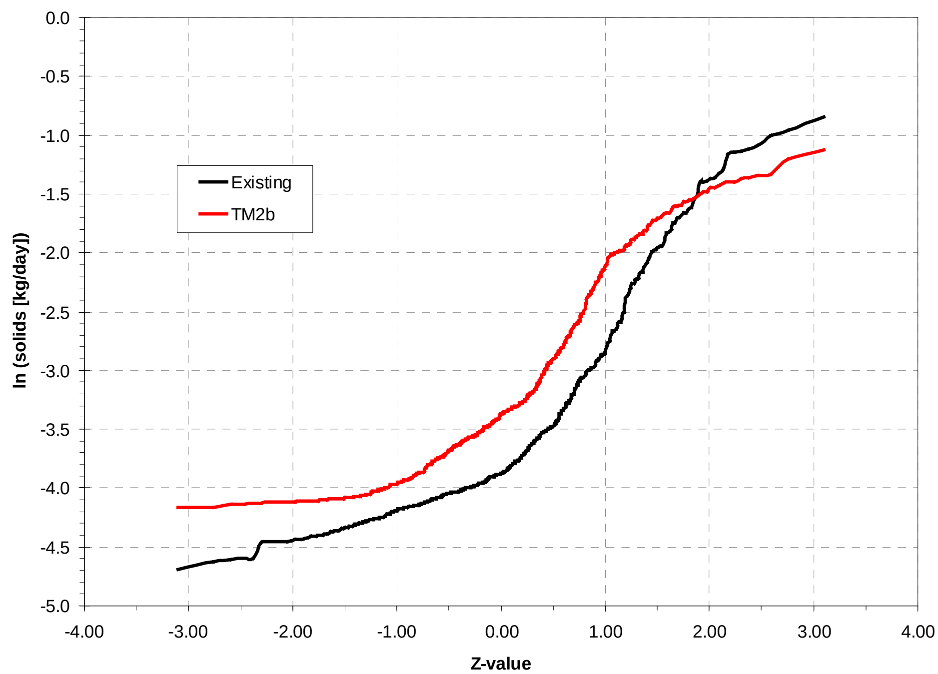

Figure 2—22. Comparison of Estimates for 1/1/89 – 6/1/90 Period: Distribution of Green Bay Watershed PCBs

2.2.2 Point Source Flows and Loads

Point source flow inputs to Green Bay are insignificant (<<< 1%) relative to tributary inflows, exchange with Lake Michigan, and direct precipitation. Point source solids loads are also considered insignificant relative to watershed solids loads and internal loads. There are no known direct point source discharges of PCBs to Green Bay. Indirect PCB loads from sources located along Green Bay tributaries, excluding the Lower Fox River, are implicitly included in the watershed PCB load estimates. For these reasons, direct point sources flow, solids loads, and PCB loads to Green Bay were treated as zero in the existing GBTOX model. The GBMSD plant flows were included as a point source in GBTOX.

The Model Evaluation Workgroup recommends that GBTOX be evaluated with point source flows, solids loads, and PCB loads represented as zero in Green Bay.

2.2.3 Internal Production

The existing GBTOX employs a gross internal solids loading approach in which loads were computed using the Green Bay Eutrophication Model (GBEUTRO). GBEUTRO is a conventional chlorophyll-based eutrophication model that computes autochthonous production (in the form of phytoplankton biomass) as a function of advective-dispersive transport, external nutrient loadings, sediment nutrient fluxes, incident solar radiation, underwater light attenuation, and water temperature. These load estimates are expressed as organic carbon equivalents for use in GBTOX.

To estimate internal solids loads for the purpose of evaluating the existing GBTOX, data related to algal growth were examined in Task 2c. In this task, an empirical approach for estimating internal solids loads was applied using primary productivity data available for 1982 (Auer et al., 1982). Internal solids production was calculated from these data for 1982 and scaled for other years using a time series of phosphorus loads, assuming a linear relationship between phosphorus loads and production. As a check, the 1982 load estimates from the empirical approach were compared to 1982 load estimates calculated using a simplified primary productivity production (SPP) approach. In the SPP approach, Secchi disk depth (which described the depth to which light penetrates the water column), light, water temperature, nutrients (phosphorus), and chlorophyll-a data were used to estimate biotic solids inputs to Green Bay.

The empirical internal solids loads estimates were converted to carbon equivalents. To convert the solids biomass to carbon equivalents, the internal solids were assumed to be 20% dissolved organic carbon (DOC) and 80% biotic carbon (BIC) (Bierman et al., 1992). These internal load estimates are presented in Technical Memorandum 2c (TM2c) (LTI, 1999b).

Table 2-15 and Figure 2-21 presents internal DOC loads for the 1989-90 simulation periods. Figure 2-23 is a graphical presentation of the internal DOC loads for the 1989-90 period. While the average loads are similar, the existing loads are 1.5 to 2 times higher than the TM2c loads during July and August. The seasonal trends in the load estimates are otherwise similar. The inverse log normal cumulative distribution functions of the daily estimates are shown in Figure 2-24. While similar for values greater than the mean, these distributions are considerably different for values less than the mean value. This is a reflection of differences in predicted loads for the months of November through March.

Table 2-16 presents internal BIC loads for the 1989-90 and 1989-95 periods. Figure 2-25 is a graphical presentation of these loads for the 1989-90 period. Again, while the average loads are similar, the existing loads are 1.5 to 2 times the TM2c loads during July and August. The inverse log normal cumulative distribution functions of the daily estimates for 1989-90 are shown in Figure 2-26. Once again, while the distributions are similar for values greater than the mean value, the distributions are considerably different for values less than the mean. This is again a reflection of the different seasonal trends in the load estimates.

Internal solids loads are an important component of the overall mass balance of solids in Green Bay. Because these loads have the potential to influence the results of short-term and long-term contaminant transport simulations, the difference in seasonal distributions between the existing loads and those presented in TM2c is considered significant. Therefore, the Model Evaluation Workgroup recommends that GBTOX be evaluated using the results of TM2c to define DOC and BIC inputs.

Table 2-15. Comparison of Estimates for the 1989-90 and 1989-95 Periods: Green Bay Internal Dissolved Organic Carbon (DOC)

Internal DOC Summary	***Existing***	***TM2c***	
	1/1/89-6/1/90	***1/1/89-6/1/90***	***1/1/89-12/31/95***
Minimum (kg/month)	223,899	1,870,842	1,099,023
Median (kg/month)	2,644,695	3,277,664	3,972,879
Mean (kg/month)	4,757,393	4,517,144	5,891,761
Maximum (kg/month)	13,119,982	11,597,382	21,406,055

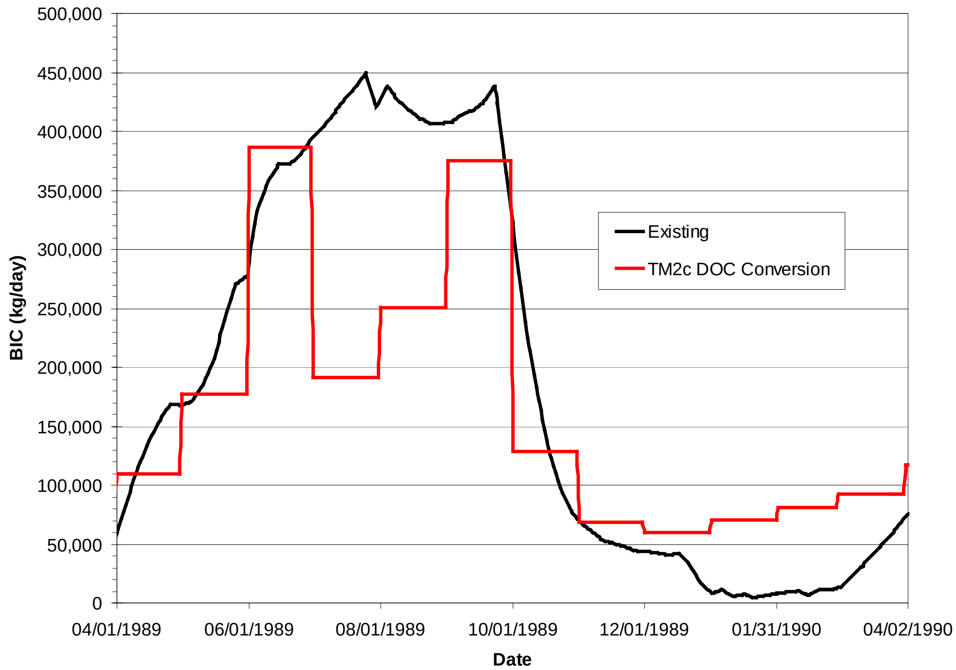

Figure 2—23. Comparison of Estimates for 1989-90 Period: Green Bay Internal Dissolved Organic Carbon (DOC)

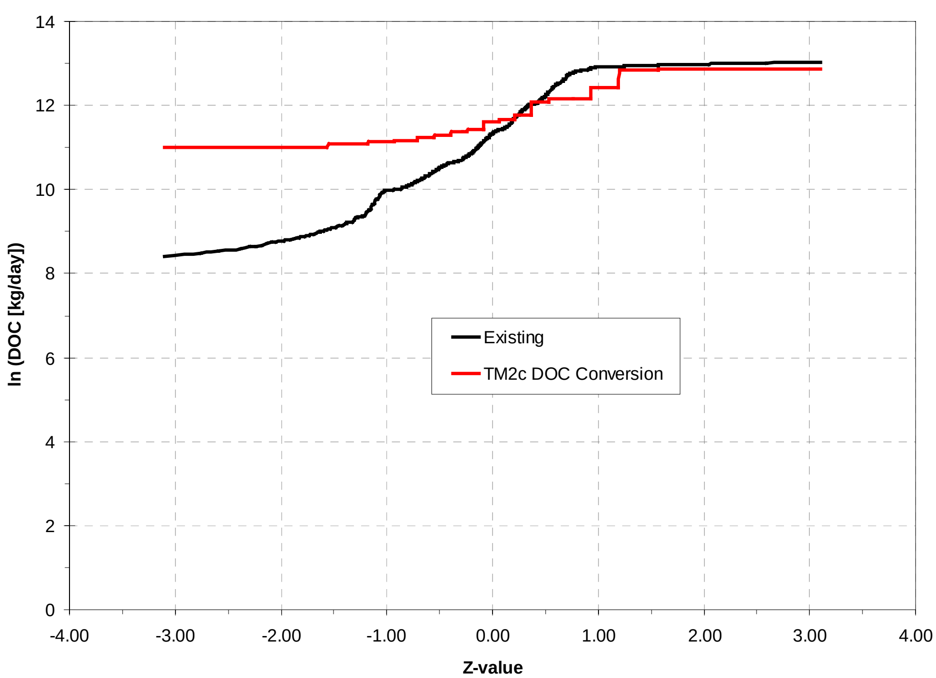

Figure 2—24. Comparison of Estimates for 1/1/89 – 6/1/90: Distribution of Green Bay Internal Dissolved Organic Carbon (DOC)

Table 2-16. Comparison of Estimates for 1989-90 and 1989-95 Periods: Green Bay Internal Biotic Carbon (BIC) Solids

Internal BIC Solids Summary	***Existing***	***TM2c***	
	1/1/89-6/1/90	***1/1/89-6/1/90***	***1/1/89-12/31/95***
Minimum (kg/month)	895,562	7,483,366	4,396,092
Median (kg/month)	10,578,859	13,110,658	15,891,516
Mean (kg/month)	19,026,154	18,068,577	23,567,045
Maximum (kg/month)	52,451,793	46,389,527	85,624,220

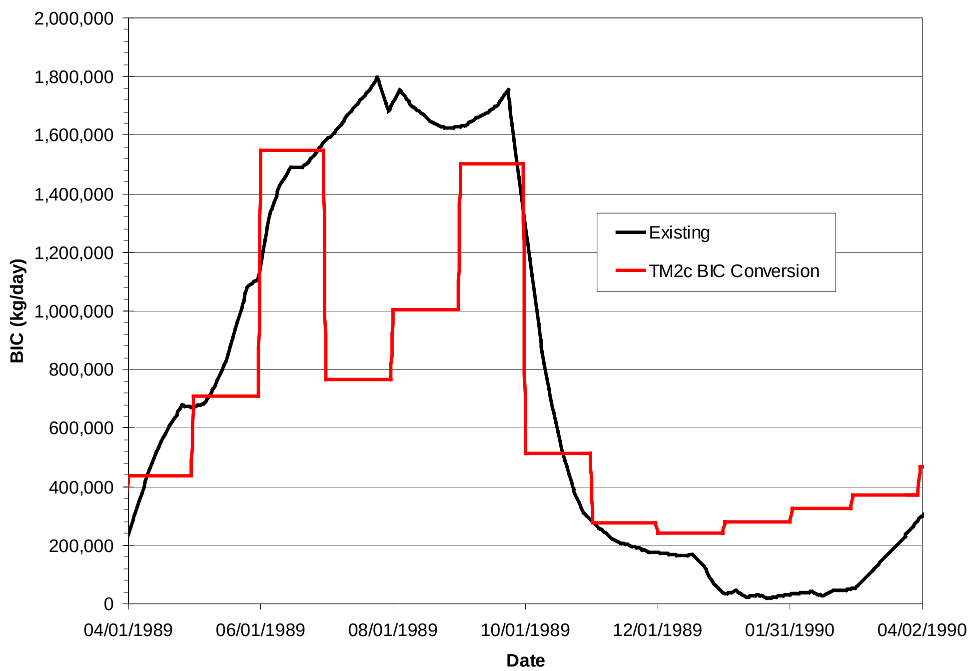

Figure 2—25. Comparison of Estimates for 1989-90 Period: Green Bay Internal Biotic Carbon (BIC) Solids

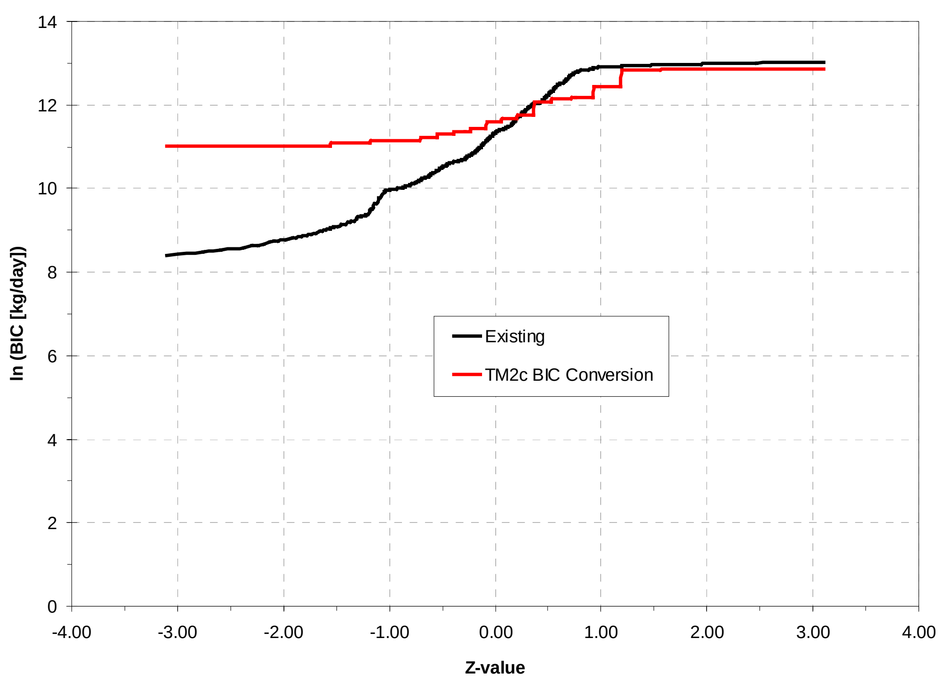

Figure 2—26. Comparison of Estimates for 1/1/89 – 6/1/90 Period: Distribution of Green Bay Internal Biotic Carbon (BIC)

3.0 INITIAL CONDITIONS

Initial conditions in the Lower Fox River and Green Bay that are important in the model evaluation process include: sediment surface areas; sediment volumes; sediment bulk density (solids concentrations); total organic carbon content (TOC) in sediment; percent sand, silt and clay in the sediment; and sediment PCB concentrations. This section provides a comparison between existing and Task 2 estimates of initial sediment conditions in the Lower Fox River and Green Bay.

3.1 LOWER FOX RIVER

Initial conditions for 1989 are specified in the existing UFRM and LFRM models for sediment surface area and volume, dry bulk density (solids concentrations), TOC, and PCB concentrations. Sediment surface areas and volumes in the existing UFRM were estimated by hand contouring 1989-1990 sediment thickness observations (which also resulted in the boundaries for each identified sediment deposit). In the existing UFRM, Steuer et al. (1995) used sediment data from 318 core sites to calculate bulk density for 762 samples. One bulk density value was used to represent each major river reach. Sediment layers that contained significant levels of PCB were assigned detailed bulk density values. In the existing UFRM, sediment organic carbon data detailed in Steuer et al. (1995) were area-weighted to arrive at TOC values for bed segments. Thiessen polygons were used to determine the area of influence for a core site. For the short-term simulations, initial PCB conditions were calculated for the existing UFRM beginning in 1989 from sediment core data collected during the GBMBS. In the UFRM, initial conditions were established by computing the area-weighted average of all observations that fell within the boundaries of identified sediment deposits (Steuer et al., 1995).

In the existing LFRM, sediment surface areas and volumes were based on an interpolation of 1993-1995 sediment thickness measurements, and, for consistency with earlier work, a total sediment thickness of 3 meters was maintained within each sediment management unit (SMU). Dry bulk density and TOC used in the existing LFRM were specified as constant values based on an average of data from 68 sediment cores at 37 locations collected from the Lower Fox River during the GBMBS. Bulk density was assigned a value of 500,000 mg/L and TOC a value of 6% for all sediment segments. For short-term simulations beginning on 1/1/89, the existing LFRM initial conditions for PCBs in each sediment segment were established by computing an inverse distance-weighted average of all observations collected during the GBMBS within each SMU (WDNR, 1997).

To estimate initial conditions for the purpose of evaluating the existing Lower Fox River models, data related to sediment bed properties in the river were examined in Task 2e. In this task, sediment thickness, surface area, and volume, bulk density, organic carbon (TOC), PCB concentrations, and other observations were used to estimate sediment bed properties for the Lower Fox River. Task 2e examined a larger database of sediment thickness, bulk density, and PCB concentrations collected since the end of the GBMBS (e.g. observations for Deposits A, POG, N, EE/GG/HH, SMU 56/57, etc.). These sediment bed property estimates are presented in

"Technical Memorandum 2e: Estimation of Lower Fox River Sediment Bed Properties" (TM2e) (WDNR, 1999b).

3.1.1 Comparison of Physical Properties of Sediment

The physical properties of the sediment bed specified in the existing Lower Fox River models (UFRM and LFRM) include sediment volume, surface area, thickness, bulk density, and organic carbon. Figures 3-1 through 3-6 present graphical comparisons of sediment properties in the existing models and TM2e estimates. There are multiple values for the area under each water column segment because initial conditions are specified for each sediment layer (segments in the vertical). Since sediments are presently the largest source of PCBs to the river water column, the representation of the sediment bed properties is an important component of PCB transport and fate in the Lower Fox River. The differences between existing and TM2e estimates and the data sets and approaches used to develop those estimates are significant. In many cases, the existing and TM2e estimates differ by 50% or more. Therefore, the Model Evaluation Workgroup recommends that TM2e estimates be used to define initial conditions for physical properties of sediment in the Lower Fox River.[3]

3.1.2 PCB Concentrations in Sediment

Particle-associated PCB concentrations in the sediment bed were also specified in the existing Lower Fox River models. Figure 3-7 through 3-10 present graphical comparisons of sediment PCB concentrations in the existing models and TM2e estimates. There are multiple values for each segment/SMU because initial conditions are specified for each sediment layer (segments in the vertical). The differences between existing and TM2e estimates are significant. In several cases, such as PCB concentrations near Deposit N (segments 12 through 14) and SMU 56/57, the existing and TM2e estimates differ by 50% or more. Therefore, the Model Evaluation Workgroup recommends that TM2e estimates be used to define initial conditions for sediment PCB concentrations in the Lower Fox River.[3]

3.2 GREEN BAY

Initial conditions for 1989 are specified in the existing Green Bay model for sediment volume, surface area, thickness, dry bulk density and organic carbon content (used to estimate PDC), and PCB concentrations. The initial conditions for sediment thickness were set to 2 cm, 2 cm and 8 cm for the three sediment segments (in the vertical) beneath each water column segment. It should also be noted that the sediment segments below water column segments 4, 7, and 8 had their surface areas reduced by 33%, 25%, and 16%, respectively. This surface area reduction was used to "mask out" shallow, nearshore areas where the bottom could not be adequately characterized because of the inability to obtain sediment cores during the GBMBS (i.e. the surface area of "transitional" zones, commonly observed in nearshore areas of large water

---

[3] The data used to estimate sediment bed properties in TM2e cover the period 1989 through 1997. Most data were collected between 1989 and 1995. As a result, the TM2e sediment bed property estimates can reasonably be used to represent initial conditions for simulations beginning any time from 1989 through approximately 1995.

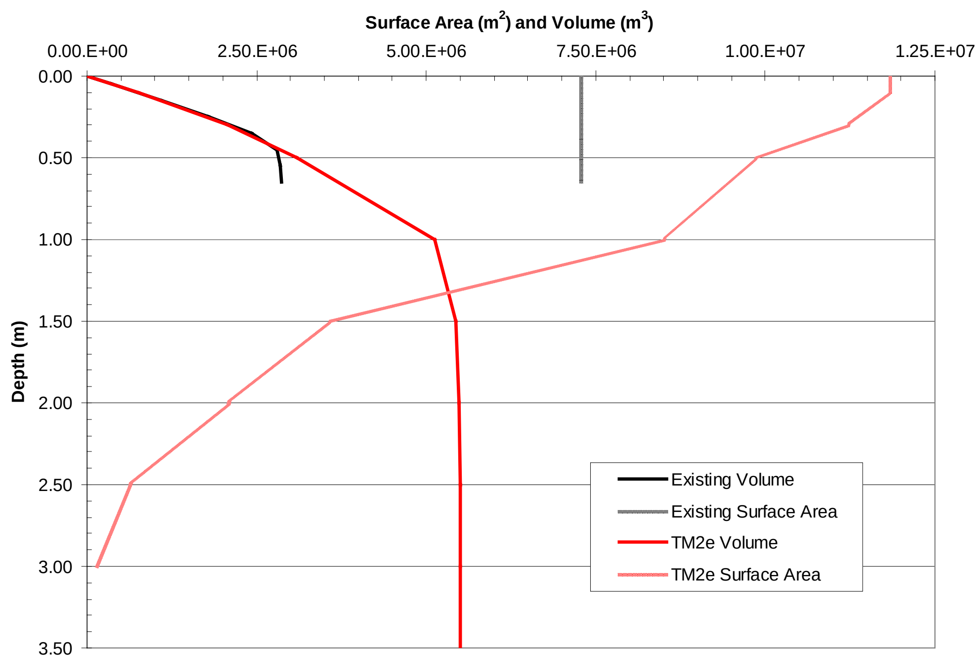

Figure 3—1. Comparison of Estimates for Initial Conditions: Sediment Surface Area and Volume Upstream of the DePere Dam

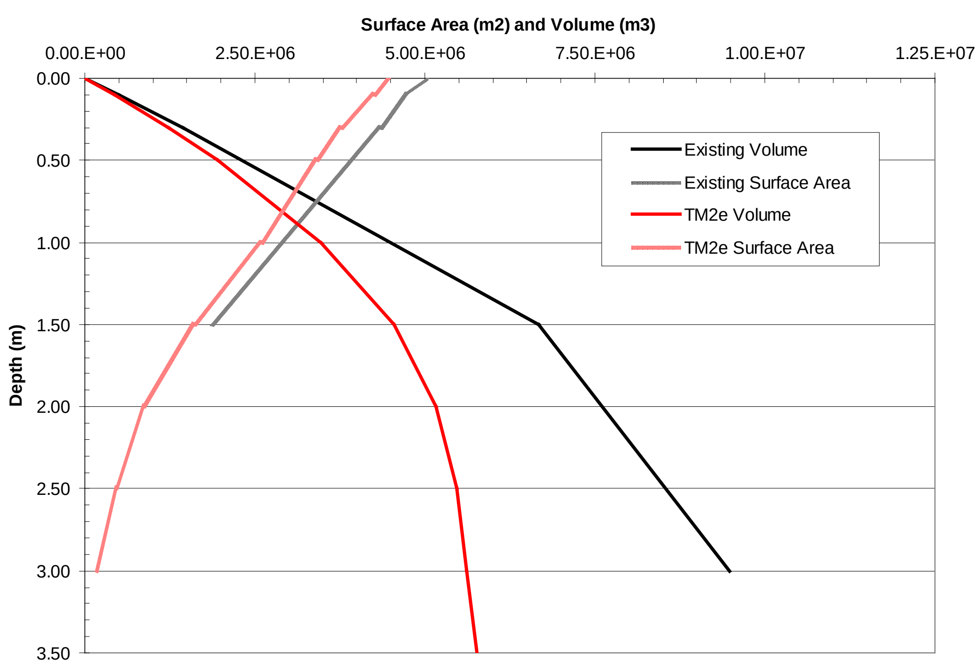

Figure 3—2. Comparison of Estimates for Initial Conditions: Sediment Surface Area and Volume Downstream of the DePere Dam

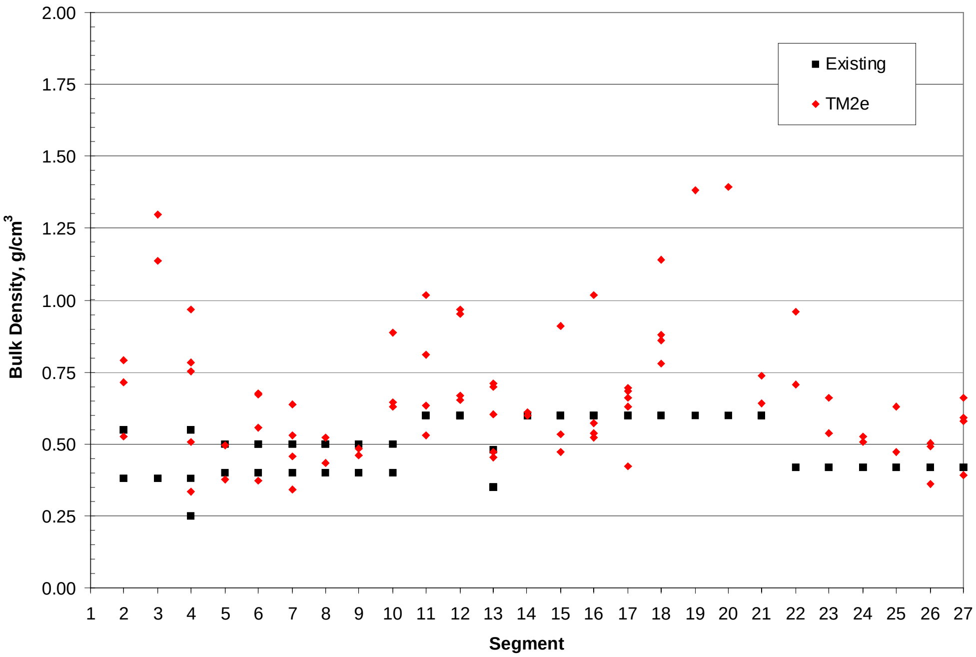

Figure 3—3. Comparison of Estimates for Initial Conditions: Sediment Dry Bulk Density Upstream of the DePere Dam

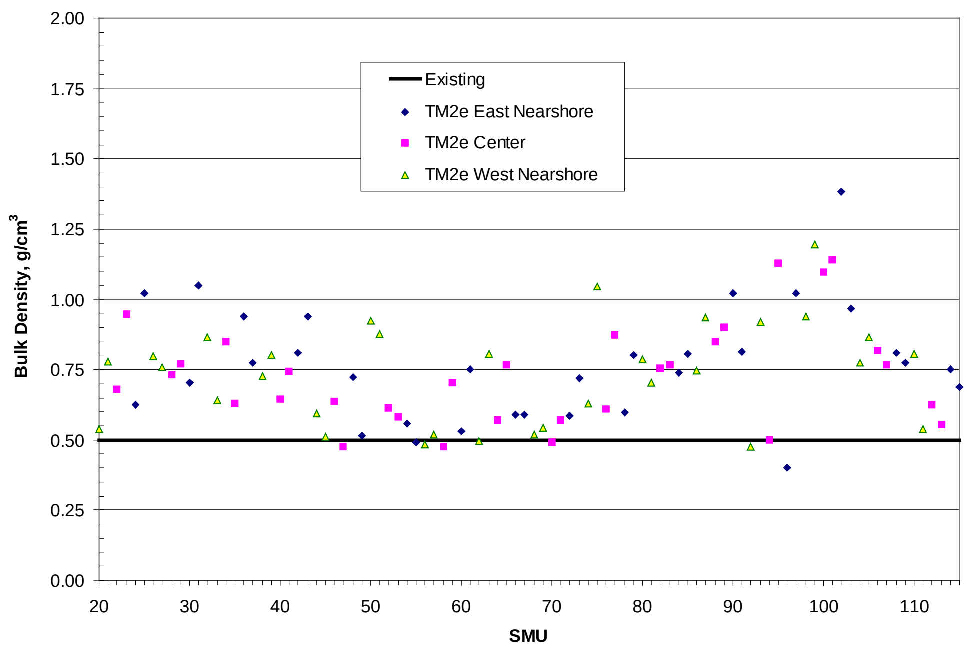

Figure 3—4. Comparison of Estimates for Initial Conditions: Sediment Dry Bulk Density Downstream of the DePere Dam

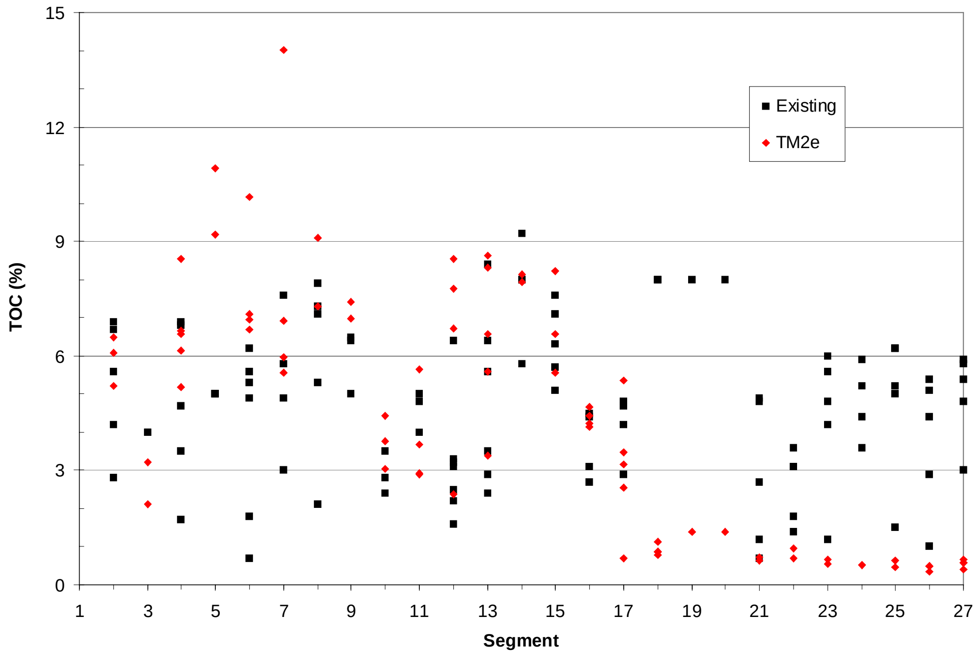

Figure 3—5. Comparison of Estimates for Initial Conditions: Sediment TOC Upstream of the DePere Dam

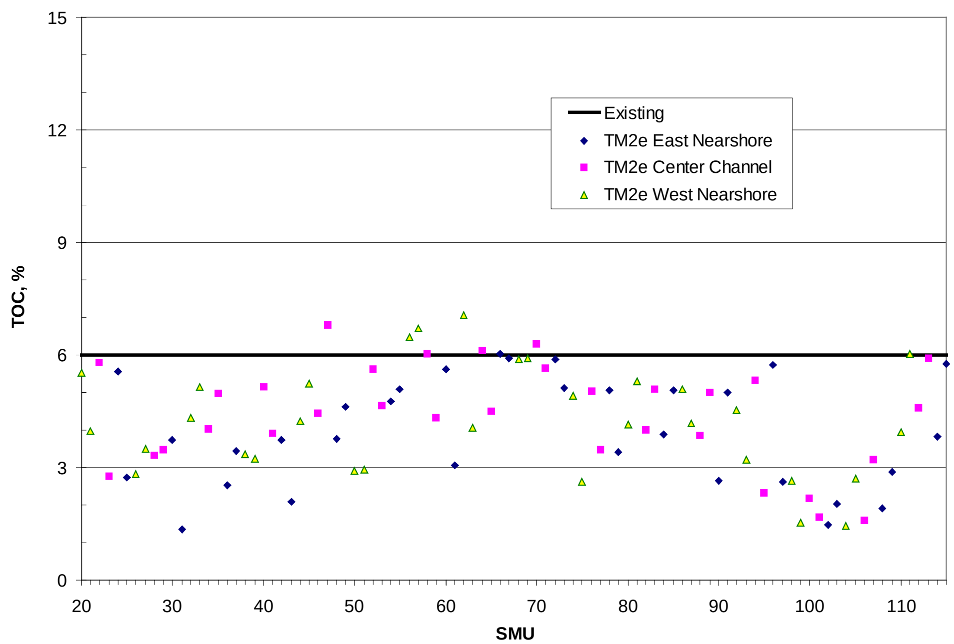

Figure 3—6. Comparison of Estimates for Initial Conditions: Sediment TOC Downstream of the DePere Dam

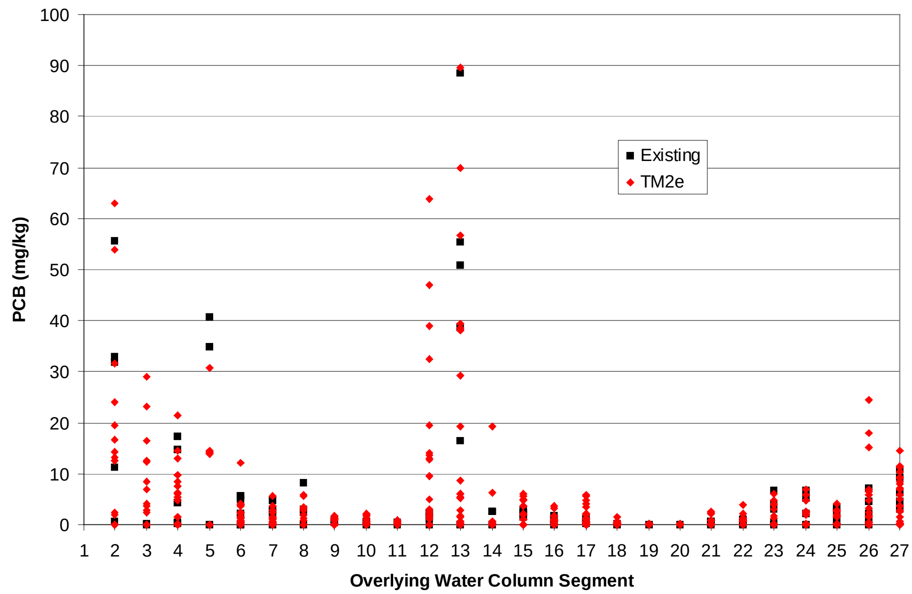

Figure 3—7. Comparison of Estimates for Initial Conditions: Sediment PCB Concentration in the Lower Fox River Upstream of the DePere Dam

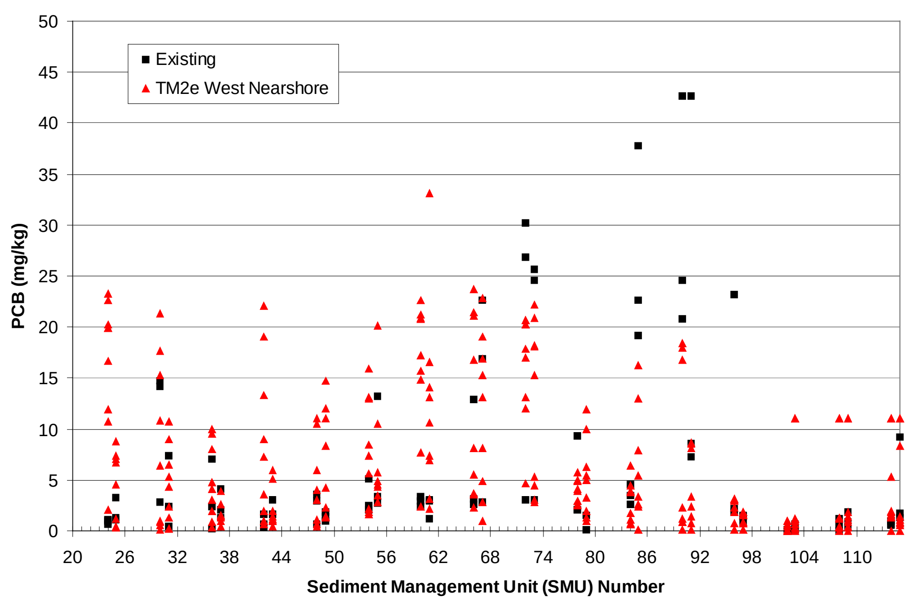

Figure 3—8. Comparison of Estimates for Initial Conditions: Sediment PCB Concentrations in the Lower Fox River Downstream of the DePere Dam, West Nearshore SMUs

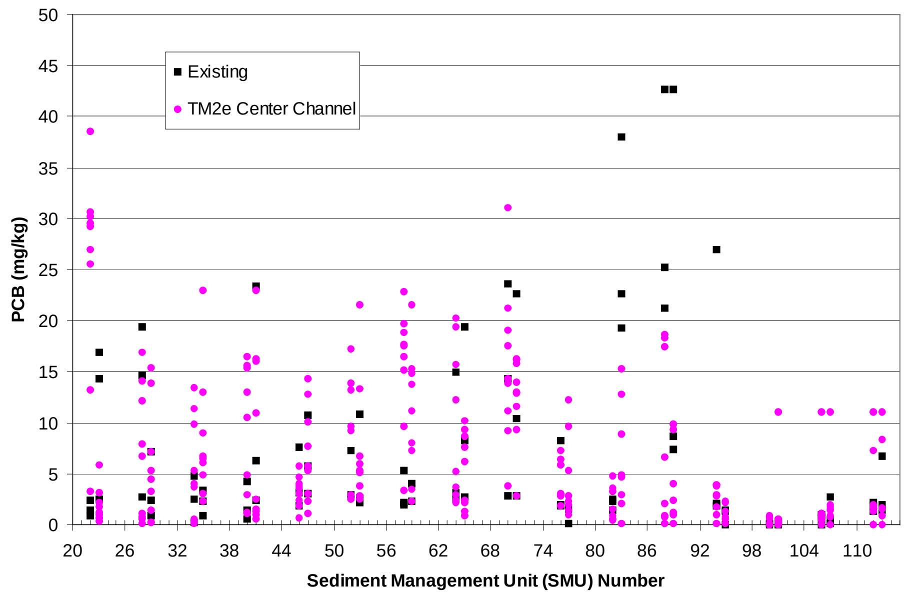

Figure 3—9. Comparison of Estimates for Initial Conditions: Sediment PCB Concentrations in the Lower Fox River Downstream of the DePere Dam, Center Channel SMUs

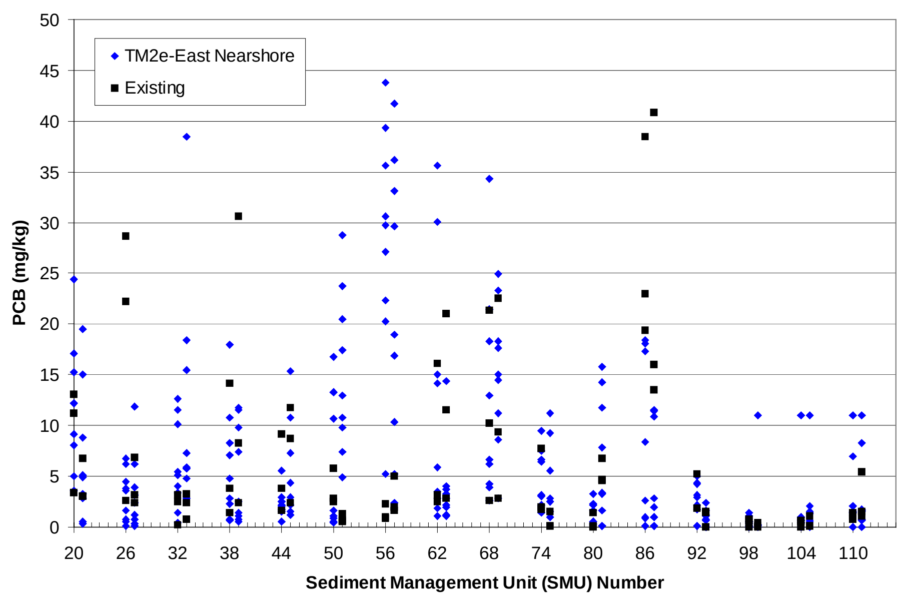

Figure 3—10. Comparison of Estimates for Initial Conditions: Sediment PCB Concentrations in the Lower Fox River Downstream of DePere Dam, East Nearshore SMUs

bodies, was excluded). The initial conditions for bulk density were determined using GBMBS. sediment sampling program data. The solids concentration for the sediment segments in a specific sediment zone was calculated by averaging the porosity values of all the sediment cores measured in the respective zones. Initial conditions for the sediment organic carbon and PCB concentrations were established from segment averages of GBMBS data collected from 1987 through 1991.

To estimate initial conditions for the purpose of evaluating the existing Green Bay models, data related to sediment bed properties in the bay were examined in Task 2f. In this task, sediment depth of analysis (a surrogate for sediment thickness), surface area, volume, bulk density, organic carbon (TOC), PCB concentration, and other observations were used to estimate sediment bed properties for Green Bay. Task 2f examined a larger data base of sediment bed property observations collected since the end of the GBMBS (often in areas not sampled during the GBMBS). These sediment bed property estimates are presented in “Technical Memorandum 2f: Estimation of Sediment Bed Properties in Green Bay” (TM2f) (WDNR, 2000).

3.2.1 Comparison of Physical Properties of Sediment

The physical properties of the sediment bed specified in the existing Green Bay model include sediment volume, surface area, thickness, bulk density, organic carbon, and percent sand, silt and clay. Figures 3-11 through 3-13 present graphical comparisons of sediment properties in the existing model and TM2f estimates. TM2f Estimates of sediment PDC were computed as the product of bulk density and TOC. Since sediments represent a considerable source of PCBs to the bay water column, the representation of the sediment bed is an important component of PCB transport and fate in Green Bay. The differences between existing and TM2f estimates and the approaches used to develop those estimates are significant. In many cases, such as sediment bulk density, the existing and TM2f estimates differ by 50% or more. Therefore, the Model Evaluation Workgroup recommends that the TM2f estimates be used to define initial conditions for physical properties of sediment in Green Bay.

3.2.2 PCB Concentrations in Sediment

Particle-associated PCB concentrations in the sediment bed were also specified in the existing Green Bay model. Figure 3-15 presents a graphical comparison of sediment PCB concentrations in the existing model and TM2f estimates. There are multiple values for each segment because initial conditions are specified for each sediment layer (segments in the vertical). The differences between existing and TM2f estimates and the approaches used to develop those estimates are significant. In many cases, such as PCB concentrations in the inner-most part of the bay, the existing and TM2f estimates differ by 50% or more. Therefore, the Model Evaluation Workgroup recommends that the TM2f estimates be used to define initial conditions for sediment PCB concentrations in Green Bay.

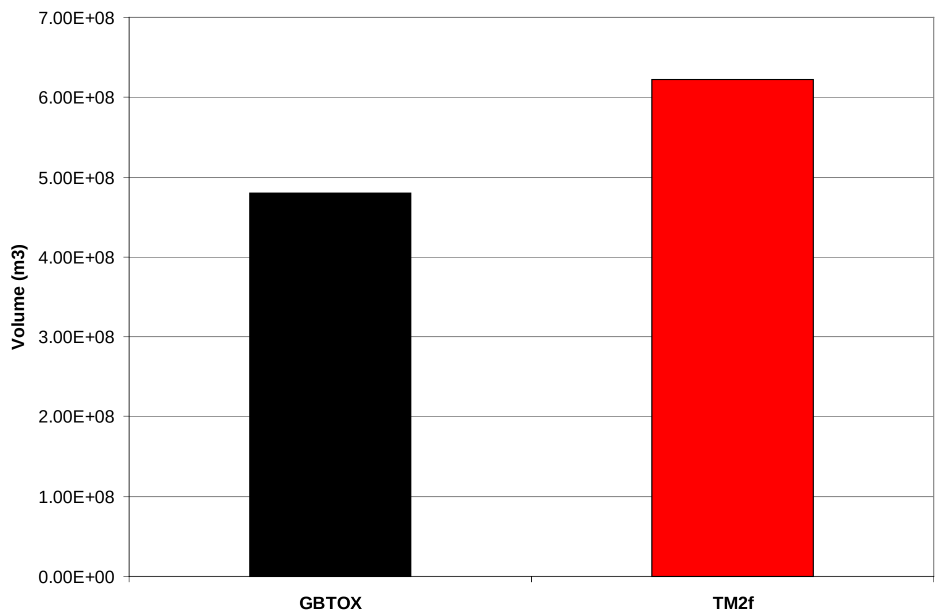

Figure 3—11. Comparison of Estimates for Sediment Volume in Green Bay

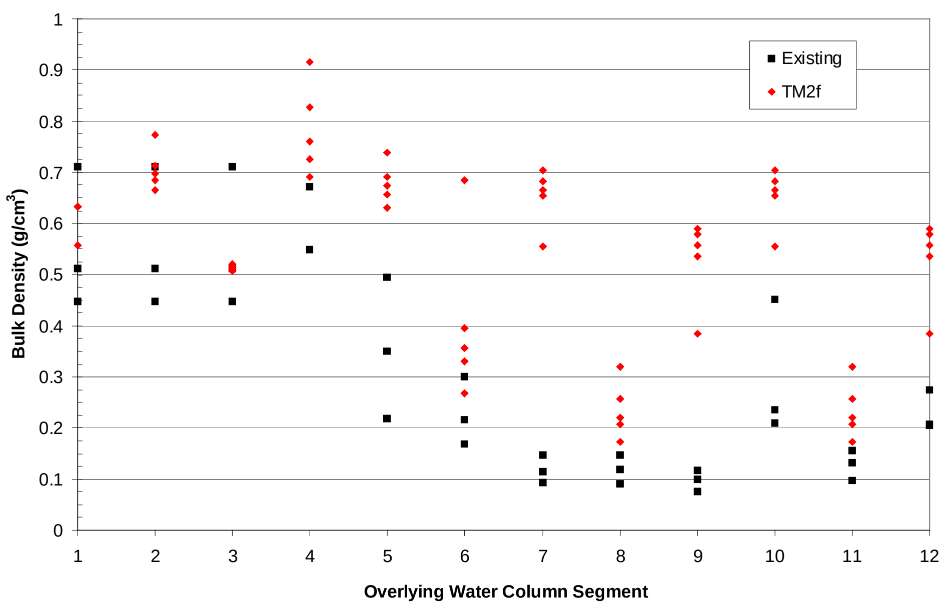

Figure 3—12. Comparison of Estimates for Sediment Bulk Density in Green Bay

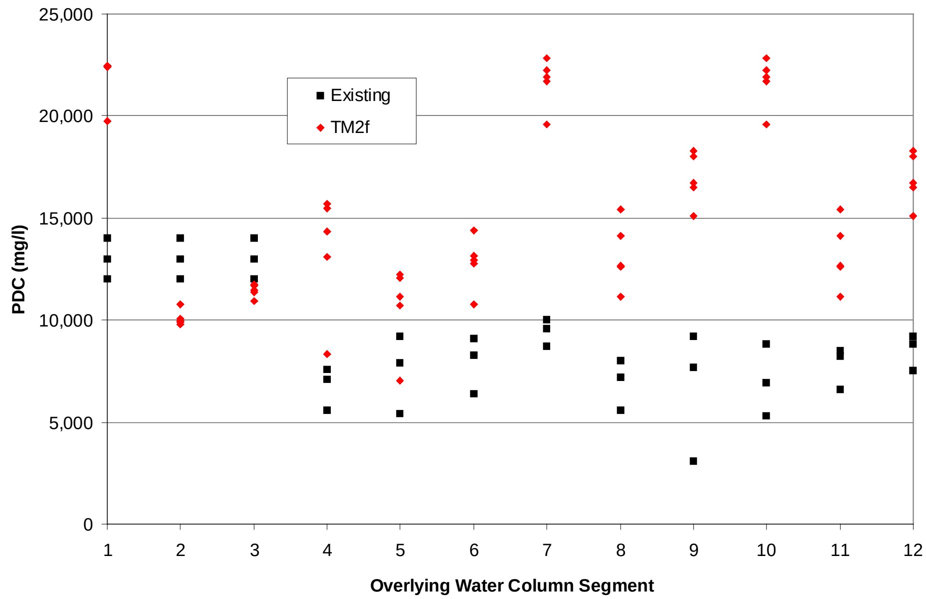

Figure 3—13. Comparison of Estimates for Sediment PDC in Green Bay

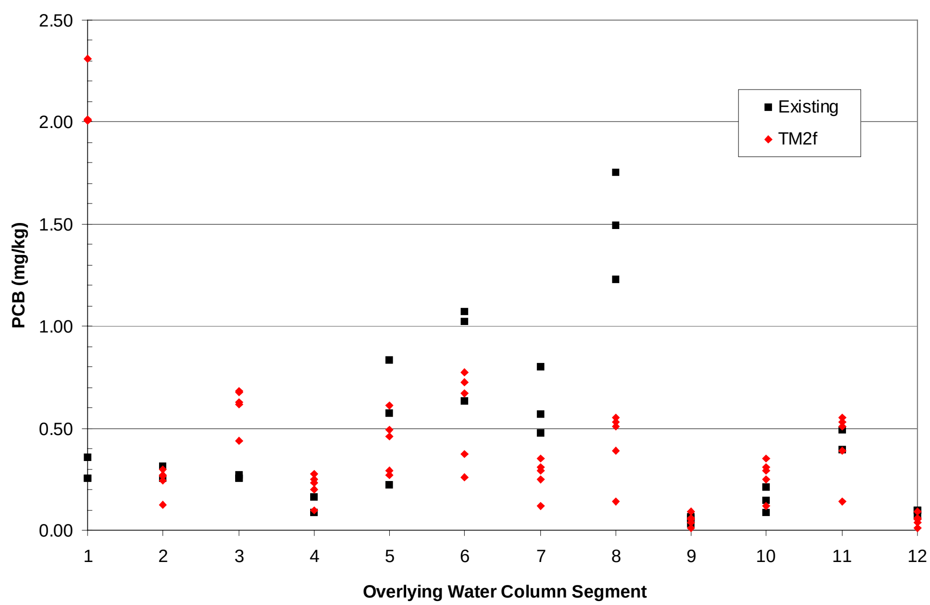

Figure 3—14. Comparison of Estimates for Sediment PCBs in Green Bay

4.0 BOUNDARY CONDITIONS

In the suite of existing models for the Lower Fox River and Green Bay, boundary conditions are specified at two main locations: 1) the upstream system boundary at Lake Winnebago; and 2) the downstream system boundary between Green Bay and Lake Michigan. At these locations, the boundary conditions that are important in the model evaluation process include: flow, suspended solids concentrations (or carbon-based equivalents: PDC, BIC, and DOC); and water column PCB concentrations. This section provides a brief examination of these boundary conditions in the Lower Fox River and Green Bay.

4.1 LOWER FOX RIVER

For the Lower Fox River, the main boundary of importance is the upstream system boundary at Lake Winnebago. This boundary is located at the upstream limit of the UFRM. In the existing UFRM, boundary conditions for water flow, suspended solids concentrations, and PCB concentrations were specified.

Note that the DePere dam is the interface between the UFRM and LFRM and represents an internal system boundary. No boundary conditions were specified at this location because all flows, solids, and PCB inputs were specified by the results (output) of the UFRM. Also note that in the existing UFRM and LFRM, inputs from all other system boundaries (i.e. the watershed) were specified as flows and loads. Analyses of those flows and loads were presented in Section 2.0.

4.1.1 Flows

In the existing UFRM, boundary conditions for the flow entering the Lower Fox River from Lake Winnebago were estimated from observations collected at the USGS gage at Rapide Croche according to the following formula:[4]

$$Q_{LW} = f_{LW} \times R_{DA} \times Q_{RC}$$

where: Q_{LW} = total flow exiting Lake Winnebago

f_{LW} = fraction of total flow assumed to originate from Lake Winnebago = 0.90

R_{DA} = drainage area ratio between gage site and the river mouth used to estimate total flow at the river mouth ≈ 1.06

Q_{RC} = observed flow at the Rapide Croche gage

[4] This formula describes the flow distribution in the existing UFRM as presented by WDNR (1997).

The total flow exiting Lake Winnebago was assumed to be equally split between the Neenah and Menasha channels.

As noted in Section 2.1.1, to estimate watershed inputs for the purpose of evaluating the existing models, flows to the Lower Fox River from Lake Winnebago were examined based on the results of TM2a. The TM2a daily flow estimates were averaged over a 4-day period with daily weighting factors of 40/20/20/20 percent. The preprocessing of TM2a watershed flows is described in Appendix A. To be consistent with the recommendation that the river models be evaluated using the TM2a watershed flows, it is also necessary to use the TM2a flow estimates for Lake Winnebago flow estimates. Therefore, the Model Evaluation Workgroup recommends that the UFRM be evaluated using the TM2a results with 4-day averaging to define boundary flows from Lake Winnebago.

4.1.2 Suspended Solids

In the existing UFRM, boundary conditions for suspended solids concentrations were estimated from 26 samples collected at the Neenah and Menasha dams during the GBMBS (see Figure 5-45 in Steuer et al. 1995). These data were a subset of a larger database of samples collected by the USGS and WDNR from 1986 through 1990. These data were generally collected using an equal-width-increment (EWI) sampling procedure and analyzed using different analytical techniques at two laboratories: the Wisconsin State Laboratory of Hygiene (SLoH) and a USGS laboratory (USGS). These data and the existing solids concentration boundary condition time series are presented in Figure 4-1. When computed as the product of concentration and flow, the effect of the suspended solids boundary condition can be expressed as a load. Using the 26 solids concentration observations from 1989 and 1990 and the flow for that period, the total solids load entering the Lower Fox River from Lake Winnebago was estimated to average 36,500 MT/year (1 MT = 1,000 kg) in the existing UFRM.

Although the tasks undertaken as part of Model Evaluation Workgroup activities do not specifically examine this boundary condition, a brief evaluation was nonetheless possible. An estimate of the annual average solids load exiting Lake Winnebago was presented by Gustin (1995). Using the data collected from 1986 through 1990, the annual total solids load entering the Lower Fox River was estimated to average 68,000 MT/year (Gustin 1995). A representation of the solids concentration boundary condition inferred from the field observations and the annual loading estimate of Gustin (i.e. when multiplied by flows for the period 1989-1995, the average load is 68,000 MT/year) is also presented in Figure 4-1. The inferred load for 1989 was estimated to be 40,500 MT/year and is about 10% greater than the existing value for that year.

The solids concentration boundary condition at Lake Winnebago is an important component of the overall mass balance of solids in the river. There is a 46% difference between the 1989 load computed from the existing boundary condition and the average estimate inferred from the results of Gustin. Because this boundary condition has the potential to influence the results of short-term and long-term contaminant transport simulations, the difference the existing solids boundary condition the boundary condition inferred from the estimate by Gustin is considered significant. Therefore, the Model Evaluation Workgroup recommends that the UFRM be evaluated using the Lake Winnebago solids boundary condition as inferred from Gustin (1995).

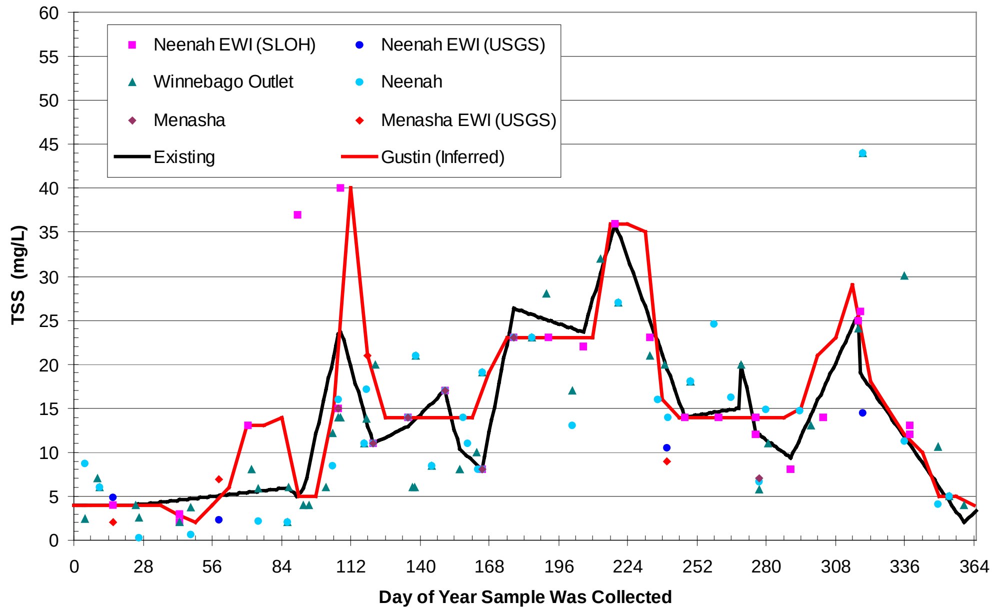

Figure 4—1. Comparison of Estimates for the Lake Winnebago Solids Concentrations Boundary Condition.

4.1.3 PCBs

In the existing UFRM, boundary conditions for PCB concentrations were estimated from 26 samples collected at the Neenah and Menasha dams during the GBMBS (see Tables 5-9 and 5-10 in Steuer et al. 1995). In addition to these samples, 10 field blanks were obtained by processing purified water through the sampling equipment. The average PCB concentration of these 26 samples was very similar to the average concentration of the 10 field blanks. As a result, the PCB concentration at the Lake Winnebago boundary was treated as zero.

The Model Evaluation Workgroup recommends that the UFRM be evaluated with the PCB concentration boundary condition at Lake Winnebago represented as zero.

4.2 GREEN BAY

For Green Bay, the main boundary of importance is the downstream system boundary at Lake Michigan. This boundary is located at the downstream limit of the GBTOX model at the interface between Green Bay and the open lake. In the existing GBTOX model, boundary conditions at Lake Michigan for water flow, and PDC, BIC, DOC, and PCB concentrations were specified. In the existing GBTOX model, inputs from all other system boundaries (the Lower Fox River, other tributaries, the watershed, etc.) were specified as flows and loads. Analyses of those flows and loads were presented in Section 2.0.

4.2.1 Flows

In the existing GBTOX model, boundary conditions for the flow entering Green Bay from Lake Michigan were estimated from the results of hydraulic transport simulations to describe the spatial and temporal distribution of a conservative tracer (chloride) (Martin et al. 1995). Currents, water temperature, wind speed, direction, and duration, and ice cover data collected during the GBMBS. Based on this approach, the mean inflow from Lake Michigan was estimated to be 8,000 m^3/s and ranged from 1,650 to 22,100 m^3/s. This inflow was then routed throughout the bay according to clockwise and counter clockwise flow routing patterns estimated by calibration.

To estimate the Lake Michigan flow boundary condition for the purpose of evaluating the existing GBTOX model, data related to currents and meteorological conditions (wind speed and direction, water and air temperature, etc.) was used to perform a hydrodynamic analysis of Green Bay. This hydrodynamic analysis is presented in "Hydrodynamics, Sediment Transport, and Sorbent Dynamics in Green Bay," (HQI, 1999). The analysis described by HQI was based on development of a three-dimensional hydrodynamic model of Green Bay (GBHydro). Based on GBHydro results, the mean inflow from Lake Michigan was estimated to be 2,334 m^3/s and ranged from 0 to 2,856 m^3/s. This inflow was then routed throughout the bay according mass, momentum, and energy conservation principles in response to observed meteorological conditions.

HQI (1999) noted that the difference in water column transport can be quantified in terms of a flushing rate. The flushing rate is a good index of model performance because it is an estimator of the time required for the bay to respond to changes in external loads. For this analysis of Green Bay, the flushing rate was defined as the time it takes 50% of the mass of a tracer released at the Lower Fox River mouth to exit the bay. In the existing GBTOX model, the flushing rate is about 150 days. In GBHydro, the flushing rate exceeds 500 days and is estimated to be on the order of 1000 days. As indicated by the flushing rate, the Lake Michigan flow boundary condition and routing pattern has the potential to influence the results of short-term and long-term contaminant transport simulations. The roughly 300% to 600% difference in flushing rate is considered significant. Therefore, the Model Evaluation Workgroup recommends that the GBHydro estimates of inflow and flow circulation patterns be used to define the boundary flows to Green Bay from Lake Michigan and routing patterns in the bay.

4.2.2 PDC, BIC, DOC, and PCB

In the existing GBTOX, boundary conditions at the interface between Green Bay Lake Michigan for the concentrations of PDC, BIC, DOC, and PCBs were estimated from GBMBS data and sometimes adjusted as part of model calibration efforts to match the observed variability in water column data (Raghunathan, 1994). These boundary conditions were not examined as part of Model Evaluation Workgroup activities or related efforts. Therefore, no evaluations of these boundary conditions were performed.

The Model Evaluation Workgroup recommends that the GBTOX model be evaluated with the existing representation of PDC, BIC, DOC, and PCB concentrations at the Lake Michigan boundary.

5.0 REFERENCES

Bannerman, R.T, A.D. Legg, and S.R. Greb. 1996. Quality of Wisconsin Stormwater, 1989-94. U.S. Geological Survey Open-File Report 96-458. U.S. Geological Survey, Madison, Wisconsin.

Bierman, V.J., Jr., J.V. DePinto, T.C. Young, P.W. Rodgers, S.C. Martin and R. Raghunathan. 1992. Development and Validation of an Integrated Exposure Model for Toxic Chemicals in Green Bay, Lake Michigan. U.S. Environmental Protection Agency, Large Lakes and Rivers Research Branch, Grosse Ile, Michigan. 265 p. plus Appendices.

Connolly, John P.; Parkerton, Thomas F.; Quadrini, James D.; Taylor, Scott T.; Thumann, Andrew J. 1992. Development and Application of a Model of PCBs in the Green Bay, Lake Michigan Walleye and Brown Trout and Their Food Webs. Environmental Engineering and Science Program, Manhattan College, Riverdale, New York. October 2, 1992.

DePinto, Joseph V.; Raghunathan, Ramesh; Sierzenga, Paul; Zhang, Xiaomi; Bierman, Victor J. Jr.; Rodgers, Paul W.; Young, Thomas C. 1994. Recalibration of GBTOX: An Integrated Exposure Model For Toxic Chemicals in Green Bay, Lake Michigan. U.S. Environmental Protection Agency, Large Lakes and Rivers Research Branch, Grosse Ile, Michigan. 32p.

Dolan, D., D. Endicott, A. H. El-Shaarawi, and K. Freeman. 1993. "Estimation of Replacement Values for Censored Data in Green Bay Point Sources," 36th Conference of the International Association for Great Lakes Research, St. Norbert College, DePere, Wisconsin. June 4-10, 1993.

Edington, D.W. and A.W. Andren. 1992. Data obtained as part of the Green Bay Mass Balance Study sampling program.

FWB2000, 1998. Technical memorandum 2a: Simulation of Historical and Projected Total Suspended Solids Loads and Flows to the Lower Fox River, N.E. Wisconsin, with the Soil and Water Assessment Tool (SWAT). Fox-Wolf Basin 2000, Appleton, Wisconsin. August 18.

Gustin, Marie-Pierre. 1995. Source, Transport and Fate of Sediments and Nutrients in the Winnebago Pool System. Ph.D. dissertation. University of Wisconsin-Milwaukee, Milwaukee, Wisconsin. August.

HQI. 1995. Addendum to Green Bay Final Report: Food Chain Model Projections. Prepared for U.S. Environmental Protection Agency, Grosse Ille, MI, by HydroQual, Inc., Mahwah, NJ.

HQI. 1999. Hydrodynamics, Sediment Transport, and Sorbent Dynamics in Green Bay. Prepared for Remediation Technologies, Inc. and the Wisconsin Department of Natural Resources. HydroQual, Inc., Mahwah, NJ. Project Number: RTCH0010.

LTI. 1999a. Technical Memorandum 2b: Computation of Watershed Solids and PCB Load Estimates for Green Bay. Limno-Tech Inc., Ann Arbor, Michigan. January 6.

LTI. 1999b. Technical Memorandum 2c: Computation of Internal Solids Loads in Green Bay and the Lower Fox River. Limno-Tech, Inc., Ann Arbor, Michigan. February 12.

Martin, S. C., Hinz, S. C., Rodgers, P. W., Bierman, V. J., Jr., DePinto, J. V., and Young, T. C. 1995. Calibration of a hydraulic transport model for Green Bay, Lake Michigan. Journal of Great Lakes Research, 21(4):599-609.

Raghunathan, Ramesh K. 1990. Development of a Dynamic Mass Balance Model for PCBs in Green Bay. M.S. Thesis. Department of Civil and Environmental Engineering, Clarkson University, Potsdam, New York.

Raghunathan, Ramesh K. 1994. The Development and Calibration of a Coupled Sorbent-Toxics Model for PCBs in Green Bay, Lake Michigan. Ph.D. dissertation. Department of Civil and Environmental Engineering, State University of New York at Buffalo, Buffalo, New York.

Steuer, Jeffrey, S. Jaeger, and D. Patterson. 1995. A Deterministic PCB Transport Model for the Lower Fox River between Lake Winnebago and DePere, Wisconsin. Wisconsin Department of Natural Resources, PUBL WR 389-95.

Velleux, Mark. 1992. An Application of the Mass Balance Approach for Estimating the Export of In-Place Pollutants from Tributary Sources to Receiving Waterbodies. M.S. Thesis. Department of Civil and Environmental Engineering. Clarkson University, Potsdam, New York.

Velleux, Mark and D. Endicott. 1994. Development of a Mass Balance Model for Estimating PCB Export from the Lower Fox River to Green Bay. J. Great Lakes Res. 20(2):416-434.

Velleux, Mark; Endicott, Douglas; Steuer, Jeffrey; Jaeger, Steven; Patterson, Dale. 1995. Long-Term Simulation of PCB Export from the Fox River to Green Bay. J. Great Lakes Res. 21(3):359-372.

WDNR. 1997. Polychlorinated Biphenyl (PCB) Contaminated Sediment in the Lower Fox River: Modeling Analysis of Selective Sediment Remediation. February, 1997. Wisconsin Department of Natural Resources, Bureau of Watershed Management.

WDNR. 1999a. Technical Memorandum 2d: Compilation and Estimation of Historical Discharges of Total Suspended Solids and PCB from Lower Fox River Point Sources. Wisconsin Department of Natural Resources, Madison, Wisconsin. February 23.

WDNR. 1999b. Technical Memorandum 2e: Estimation of Lower Fox River Sediment Bed Properties. Wisconsin Department of Natural Resources, Madison, Wisconsin. March 31.

WDNR. 2000. Technical Memorandum 2f: Estimation of Sediment Bed Properties for Green Bay. Wisconsin Department of Natural Resources, Madison, Wisconsin. December 15.

APPENDIX A. PREPROCESSING OF TM2A WATERSHED ESTIMATES

INTRODUCTION

Technical Memorandum 2a (TM2a), "Simulation of historical and projected total suspended solids loads and flows to the Lower Fox River, N.E. Wisconsin, with the Soil and Water Assessment Tool (SWAT)" was prepared by Fox-Wolf Basin 2000. The purpose of TM2a was to estimate watershed flows and solids loading to the Lower Fox River from watershed sources between Lake Winnebago and the river mouth. To complete the water balance for the Lower Fox River, flow (discharge) from Lake Winnebago must also be estimated. Lake Winnebago discharge estimates were computed from observed flows at a downstream gaging station and corresponding TM2a flow estimates. However, to prevent negative flow estimates at Lake Winnebago, the TM2a watershed flow estimates required preprocessing. For consistency, TM2a solids load estimates were processed in the same manner since the loads were computed from the flows. The preprocessing of TM2a watershed flows is described in detail in this appendix.

To estimate flows from Lake Winnebago, the TM2a flow estimates were subtracted from the flows recorded for the USGS gage at Rapide Croche near Wrightstown, located approximately 19 miles downstream of Lake Winnebago. To prevent negative flow estimates, daily TM2a flows were averaged over a 4-day period with daily weighting factors of 40/20/20/20 percent. In other words, for watershed flows estimated in TM2a to occur on Day 1, 40% is assigned to Day 1, and Days 2-4 each receive 20% of the TM2a Day 1 flow.

Lake Winnebago flows were estimated by subtracting the sum of the watershed flows estimated in TM2a for the portion of the river basin between Rapide Croche and Lake Winnebago from the Rapide Croche gage data. While the Rapide Croche site is the long-term flow gaging location for the river, it should be noted that gage readings are available at several locations during the short-term simulation period (1989-1995). However, prior to 1989, the Rapide Croche gage was the only gage in operation. Therefore, to develop a consistent approach for estimating Lake Winnebago flows for any time period (such as a hindcast simulation) it is necessary to base flow estimates on the Rapide Croche gage data.

The resulting daily flow estimates at Lake Winnebago include several negative values due to TM2a watershed flow estimates that exceed the recorded gage flow at Rapide Croche. An adjustment method was developed to prevent these negative flow estimates. The following discussion includes:

1. The approach and basis for preprocessing TM2a watershed flow estimates;

2. An evaluation of the preprocessed TM2a flows and the resulting Lake Winnebago flow estimates;

3. A comparison of the relative magnitude of preprocessed TM2a flows to mainstem flow in the Lower Fox River; and

4. A comparison of the flow estimates in the existing Lower Fox River Model and flow estimates based on preprocessed TM2a flows.

DEVELOPMENT OF THE PREPROCESSING APPROACH

Assessment of Total TM2a Flow Estimates

When raw TM2a flow estimates are subtracted from observed flows at the Rapide Croche gage, negative flow estimates for Lake Winnebago result. Before a preprocessing approach could be developed, it was first necessary to examine the overall reasonableness of TM2a flow estimates. This examination was performed by comparing the sum of TM2a flow estimates and the observed flow for the USGS gage at Lutz Park (at Appleton) to the observed flow for the USGS gage at the river mouth (at Green Bay). The sum of the flow at Lutz Park and TM2a flow estimates (between Lutz Park and the river mouth) provide an estimate of the flow at the river mouth. Therefore, if TM2a flow estimates are reasonable, the sum of the Lutz Park gaged flow and the TM2a flow estimate should roughly equal (but not exceed) the gaged flow at the river mouth.

The average gaged flow at Lutz Park was 135.1 m^3/s. The average TM2a watershed flow estimate between Lutz Park and the river mouth was 7.6 m^3/s. The sum of these values is 142.7 m^3/s. The average gaged flow at the mouth was 149.6 m^3/s. The summed value is 95% of the averaged value at the river mouth. This indicates that the raw TM2a flow estimates are reasonable. Therefore, the negative flow estimates at Lake Winnebago that result from subtracting the raw (not averaged) TM2a flows from the Rapide Croche gage do not appear to be a result of a general over-estimation of flows in TM2a.

Basis for Selection of the 4-Day Running Average Approach

Once the overall reasonableness of the flow estimates was confirmed, techniques to adjust TM2a flows while preserving the total flow estimates were evaluated. As discussed in TM2a, averaging of estimated watershed flows may be necessary to better match observations. For calibration to Duck Creek data, TM2a employed a 4-day running average approach with weighting factors of 0/25/65/10% to best match model results to measured flows for this large sub-watershed. Given use of a 4-day running average approach for the Duck Creek sub-watershed flow estimates, this approach was extended to TM2a flow estimates for the sub-watershed contributing flow to the Lower Fox River.

Unfortunately, when the weighting factors used for the Duck Creek sub-watershed are applied to TM2a flow estimates between Lake Winnebago and Rapide Croche, negative flow estimates at Lake Winnebago still result. Further, estimated TM2a peak watershed flows in this reach correspond well with peak flows at the Rapide Croche gage. Therefore, unlike the flow averaging performed for the Duck Creek sub-watershed, the selected weighting factors should maximize the weight given to flows for Day 1 of the averaging period without resulting in either:

1) negative flow estimates for Lake Winnebago; or 2) flow values less than expected conditions given Lake Winnebago dam management and regulation of water levels. As a result of these considerations, it was therefore necessary to explore other combinations of weighting factors to perform flow estimate averaging.

Lake Winnebago Dam Management and Water Level Regulation Operations

A federal dam at Menasha and a private dam at Neenah control the discharge from Lake Winnebago. Therefore, assessment of Lake Winnebago flow estimates requires an understanding of the regulation activities. Information available on the U.S. Army Corps of Engineers (USACE) Detroit District website (www.lre.usace.army.mil/info.html) summarizes the regulation plan for Lake Winnebago. There is no quantification of a minimum flow. However, the regulation plan states that flow in the Lower Fox River falls to levels near 2,000 cfs (57 m^3/s) during the warm summer months. In periods of extreme drought, flows may remain below 1,000 cfs (28 m^3/s) for weeks.

Selection of Weighting Factors for the 4-Day Running Average Approach

A range of weighting factors for the 4-day averaging approach were evaluated by calculating flow estimates for Lake Winnebago. Given USACE regulation activities, the estimated flow from Lake Winnebago for any given set of weighting factors should yield a summer flow of approximately 2,000 cfs and a a minimum flow of approximately 1,000 cfs. Weighting factors of 40/20/20/20 percent met this requirement. These weighting factors yielded a minimum daily flow at Lake Winnebago during the short-term simulation period of 978 cfs (~28 m^3/s). Twelve percent (approximately 1-1/2 months per year) of the flows fall below 2,000 cfs (57 m^3/s). These values satisfactorily correspond to expected flows conditions given USACE dam management and regulation of water levels in Lake Winnebago.

DISCUSSION OF RESULTS

Elimination of Negative Flow Estimates at Lake Winnebago

Flow at Lake Winnebago was estimated by computing the difference between the gaged flows at Rapide Croche and the sum of the preprocessed (4-day averaged) TM2a watershed flow estimates between the lake and the gage location. The gage at Rapide Croche provides a long history of flow measurements on the Lower Fox River. The 4-day averaging approach (with weighting factors of 40/20/20/20) applied to the TM2a flows eliminates all negative values from the Lake Winnebago flow estimates. This preprocessing adjustment of TM2a flow estimates also preserves the match between the estimated and gaged flows at this location.

Correlation Between Estimated and Gaged Flows

Estimated flows, both with and without the averaging of TM2a results, were compared to gage data to assess the impact of the averaging on the overall fit of the flow estimates to gage data. Comparisons were made at Lutz Park and the river mouth. Table A.1 summarizes the squared correlation coefficient (R^2) for these locations. The 4-day averaging has little impact on the overall correlation.

Ratio of Estimated Lake Winnebago Flow to Rapide Croche Gage

The distribution of daily ratios of estimated Lake Winnebago flows to the Rapide Croche gage flows is plotted in Figure A.1. The figure shows the cumulative frequency normalized to the total number of observations. This ratio reflects the portion of the gaged flow at Rapide Croche that is originates from Lake Winnebago. This ratio is greater than 0.90 more than 96% of the time. This indicates that the flow at Rapide Croche predominantly consists of flow from Lake Winnebago on most days. The minimum ratio of estimated Lake Winnebago flow to Rapide Croche flow is 0.38. This is reflective of conditions such as following large rainfall-runoff events in which watershed contributions between Lake Winnebago and Rapide Croche are significant to the total flow at Rapide Croche.

Figure A.1 is useful in assessing the significance of the watershed flows estimated by TM2a. If mainstem flow is defined by the gage at Rapide Croche, Figure A.1 indicates the contribution of watershed flows above Rapide Croche to mainstem flow. Table A.2 summarizes this contribution.

Ratio of Rapide Croche Gage to Estimated Flow at the Mouth

To assess the significance of averaged TM2a watershed flows downstream of Rapide Croche, Figure A.2 plots the distribution of daily ratios of Rapide Croche gage flow to estimated flow at the mouth. Table A.3 summarizes the results.

As shown in Tables A.2 and A.3, the frequency of time in which watershed flows estimated by TM2a contribute greatly to mainstem flow (as defined by the gage at Rapide Croche) is relatively insignificant. However, for a limited number of days the watershed flows do contribute significantly to the mainstem flow. For example, on three days during the short-term simulation period, the estimated flow at the mouth is at least twice the gaged flow at Rapide Croche.

Table A.1. Correlation of Estimated vs. Gaged flows for the Short-Term Simulation Period.

Flow Estimate	***Squared Correlation Coefficient (R^2)***	
	Lutz Park	***Mouth***
Raw TM2a Flow Estimate (no averaging) vs. Gaged Flow	0.9504	0.9131
Average TM2a Flow Estimate (40/20/20/20%) vs. Gaged Flow	0.9518	0.9085

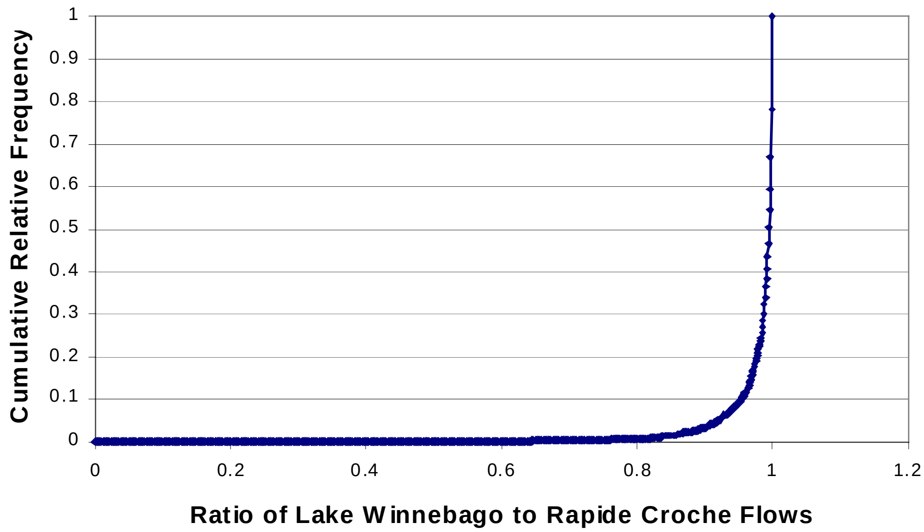

Figure A.1. Distribution of Estimated Lake Winnebago to Rapide Croche Flow Ratios for the Short-Term Simulation Period (based on 4-day averaging of daily TM2a results).

Table A.2. Contribution of Estimated Watershed Flows (based on 4-day averaging of daily TM2a results) to Mainstem Flow - Above Rapide Croche.

Minimum contribution of watershed flows to mainstem flow (%)	*Frequency of time (%)*
10	3.4
20	0.67
30	0.35
40	0.12
50	0.039
max 62	

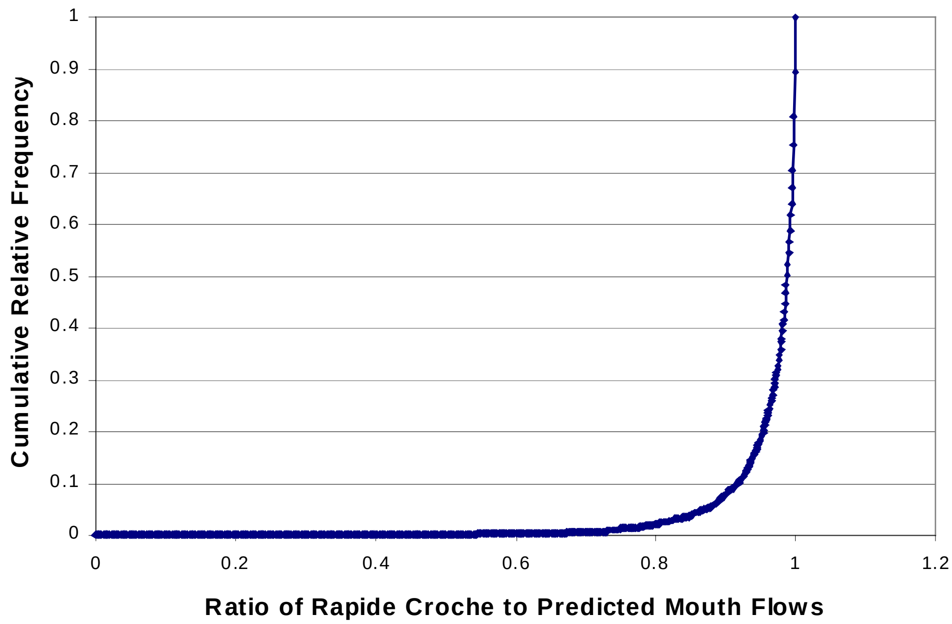

Figure A.2. Distribution of Rapide Croche to Estimated Mouth Flow Ratios for the Short-Term Simulation Period (based on 4-day averaging of daily TM2a results).

Table A.3. Contribution of Estimated Watershed Flows (based on 4-day averaging of daily TM2a results) to Mainstem Flow - Below Rapide Croche.

Minimum contribution of watershed flows to mainstem flow (%) (% of Rapide Croche flow to estimated mouth flow)	*Frequency of time (%)*
10 (90.9)	8.9
25 (80.0)	2.0
50 (66.7)	0.35
75 (57.1)	0.16
100 (50.0)	0.12
max 121 (45.3)	-

SUMMARY OF RESULTS

The TM2a watershed flows were adjusted using a 4-day running average with daily weighting factors of 40/20/20/20 percent. In other words, for watershed flows estimated in TM2a to occur on Day 1, 40% is included in the adjusted flows on Day 1. Days 2-4 each include 20% of the Day 1 flow.

This method of preprocessing the TM2a flow estimates has the following benefits:

- Negative flow estimates at Lake Winnebago are eliminated;

- The estimated flows at Rapide Croche match the gage data;

- The total flow estimates in TM2a are preserved;

- The selected averaging approach follows the precedent of 4-day averaging used in TM2a calibration; and

- The minimum flow estimated at Lake Winnebago (~28 m^3/s for the short-term simulation period) is representative of the general operation conditions given USACE Lake Winnebago for dam management and regulation of water levels.

Comparison of preprocessed TM2a watershed flow estimates to mainstem flows shows that on certain days (with water runoff following rainfall events) in the short-term simulation period the TM2a flow contributes more than 50% to the estimated flow at the mouth.